DS2 PLT Measurements in Crieff

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Contents

Section		Page
1	Background	4
2	Introduction	6
3	Summary of findings	8
4	Test notes	9
5	Measurement results	13
6	Observations and conclusions	34
7	Calibrated measuring equipment	37
8	References	38
9	Acknowledgements	39
Annex A	List of abbreviations	40
Annex B	Measurement location photographs	41

Summary

This project was designed to update Ofcom on the nature and extent of the unavoidable radio frequency leakage emissions that radiate from modern Power Line Telecommunications networks. Particular interests were the rate at which PLT leakage emission levels decay with distance from their source and the effectiveness of any mitigation measures that can be applied by PLT manufacturers and operators to reduce any adverse impact of these leakage emissions on radio reception.

This report covers the second part of the project and is specific to the situation at Crieff in Scotland where Scottish and Southern Energy plc were undertaking a commercial trial of a DS2 access PLT product that is based on multi-carrier OFDM signal architecture.

A significant feature of the DS2 access PLT product is a built-in capability of having programmed notches inserted within the broadband downstream spectrum for the purpose of reducing launch power levels, within specified frequency bands, by up to 30dB. This aspect was the main focus of this work.

Swept frequency measurements of the conducted output of the DS2 Head End modem were made to characterise the broadband downstream spectrum and to examine the notching capabilities. It was found that both the 20dB and 30dB notches performed as claimed but that the application of the 30dB notch resulted in an appreciable loss of wanted bandwidth.

A low noise loop antenna was used to make swept frequency measurements of radiated leakage emissions within the Ancaster Road area of Crieff, where the DS2 PLT network was deployed. It was found that, even at the maximum power setting of the Head End modem, the notched spectrum bandwidth and depth remained unchanged when measured as a radiated emission.

The practical benefits of the notching technique have been shown in this report as several simple examples where radio signals, previously buried under DS2 leakage emissions, were uncovered by notching.

Leakage emission levels were generally found to be in accordance with expectations having regard to the measurement position, distance from the source, power applied and in particular, the results of previous work on radiated emissions from PLT networks.

The flexibility of the DS2 product, with its programmable spectrum mask and downstream notching capability, represents a significant step towards a more EMC friendly PLT solution.

Section 1

Background

Power Line Telecommunications (PLT), Power Line Communications (PLC) and Broadband *over* Power Line (BPL) are all terms used to refer to the process of delivering high frequency broadband data over existing electricity supply cables, on a secondary use basis. The generic term PLT will be used in this report.

PLT products are designed to provide broadband internet access using electricity distribution networks as a transmission medium. In concept, PLT has some similarities with ADSL that also delivers high frequency broadband data, using existing infrastructure cables on a secondary use basis.

Access PLT networks feature high frequency internet signals that are passed between an electricity sub-station and all the PLT customers connected to it. A typical 500 kVA substation can serve up to about 200 electricity users, situated within a 200 metre radius, with the potential PLT customer base being a small percentage of these. To serve these customers, each PLT enabled electricity sub-station must be connected to an ISP via a dedicated high capacity link.

In principle, PLT is in competition with ADSL and Cable although, in practice, the PLT market share in the UK is currently extremely small as there are only a few isolated commercial trial networks in operation. One reason for this is concern over leakage emission levels. Although efficient for their primary purpose, electricity supply cables are not designed, screened or balanced for high frequency use and in this application they produce significant leakage emissions. These emissions have the potential to interfere with the reception of radio communication services, including short wave broadcasts.

This potential for interference from PLT networks was first raised by RA during 1997 as a result of leakage emission measurements taken at the first UK trials of PLT, by United Utilities, in Manchester. The interference aspect of PLT has been widely debated in many discussion groups since. The PLT industry has participated in these discussions from the outset and responded to the interference issue by focussing on more efficient modulation techniques. These permit operation over a wider bandwidth with less power spectral density than some early PLT deployments. Other measures, such as the use of quasi-balanced signal coupling and the use of intermediate repeaters have also reduced leakage emission levels in some applications.

The PLT interference issue is contentious and remains under discussion within the EC and elsewhere. Various radiated emission limits have been proposed, either for system compliance or for the purposes of adjudication in cases of reported interference, but currently none can satisfy a dual objective of protecting radio reception whilst, at the same time, allowing PLT to operate in a commercially viable manner.

The advent of multi-carrier PLT signal architecture has lead to a comparatively recent development in which pre-defined frequency bands within the broadband PLT spectrum can be notched to lower the launch power spectral density. The notched frequency bands have significantly reduced leakage levels. This technique is being promoted by

PLT manufacturers and operators as a useful mitigation measure in cases where nearby radio receivers are experiencing interference from PLT signal leakage even though the unnotched leakage levels may be within the currently proposed emission limits.

The second generation DS2 PLT equipment, deployed by S&SE at Crieff, has a notching capability that is examined in this report.

Section 2

Introduction

Scottish and Southern Energy's PLT Trials

Scottish and Southern Energy plc, a major UK power utility, is currently conducting several trials of access PLT products. Small scale trials are in place at Crieff and Campbeltown in Scotland with larger trials underway at Stonehaven in Scotland and at Winchester in England.

S&SE's promotional material for their PLT based broadband products can be found at:

http://www.hydro.co.uk/broadband/index.asp

http://www.southern-electric.co.uk/broadband/

Some of these trials are receiving external support, including that from central government through the DTI broadband fund. More details can be found at:

http://www.ssetelecom.co.uk/news/index.asp

http://www.scottish-enterprise.com/sedotcom_home/services-to-business/broadband/broadband-news/power_line_trial.htm

Access PLT Networks in Crieff

S&SE are currently using and evaluating equipment from three different PLT manufacturers, Ascom, MainNet and more recently DS2.

The Ascom equipment uses GMSK signal architecture, MainNet equipment uses DSSS signal architecture and the DS2 equipment uses OFDM signal architecture. The RA had previously undertaken leakage emission measurements at S&SE's trial PLT network at Crieff when both Ascom and MainNet PLT equipment were in use. (**Ref 1**) In a later development, S&SE has installed multi-carrier PLT equipment using a chipset developed by the Spanish company DS2. Measurement of the DS2 based access PLT network at Crieff is the subject of this work.

Measurement Objectives

Project 793 was designed to update Ofcom on the nature and extent of the unavoidable radio frequency leakage emissions that radiate from modern Power Line Telecommunications networks.

Particular interests were the rate at which PLT leakage emission levels decay with distance from their source and the effectiveness of any mitigation measures that can be applied by PLT manufacturers and operators to reduce any adverse impact of these leakage emissions on radio reception.

This second part of project (793/2) is specific to the situation at Crieff where Scottish and Southern Energy plc are currently undertaking a commercial trial of the DS2 access PLT product that is based on multi-carrier OFDM signal architecture.

The primary objective of this work was:

1.) To examine the DS2 PLT spectrum and characterise the notching capabilities provided by the chipset in order to assess its potential usefulness as an interference mitigation measure.

Other objectives were:

2.) To measure the level of leakage emissions in the immediate vicinity of both the DS2 access PLT network and PLT customer premises.

This information was required in order to compare PLT leakage emission levels with those measured elsewhere and to make comparisons with emission limits under discussion within Europe.

3.) To assess the effect of DS2 leakage emissions on short wave broadcast reception within the domestic environment.

It is considered that short wave broadcast reception within the domestic environment is the most likely interference scenario to occur due to PLT deployment. To address this issue, it was agreed that the BBC would be invited to use the two PLT customer premises, made available by S&SE, to continue their previous work on the effect of PLT leakage emissions on both AM broadcast reception and reception of the new Digital Radio Mondiale services. (**Ref. 2**)

The BBC took up this invitation and a recent BBC R&D White Paper on the compatibility between PLT and Broadcast reception contains some references to this work. (**Ref 3**)

A further BBC report, specific to their recent work at Crieff, is expected.

Section 3

Summary of findings

Notching

The notches requested by Ofcom were applied to both the downstream access spectrum transmitted from the Head End master unit in Ancaster Road substation and separately to the downstream in-house spectrum transmitted from the Home Gateway master units in PLT customer premises. Notches could not be applied to the upstream spectrum.

Measurements of the conducted DS2 signal at Ancaster Road substation confirmed that the depth of both 20dB and 30dB notches, was as claimed but that the application of the 30dB notch resulted in an appreciable loss of wanted bandwidth.

A low noise loop antenna was used to make swept frequency measurements of radiated leakage emissions within the Ancaster Rd area of Crieff where the DS2 PLT network was deployed. It was found that, where there were sufficient leakage levels above the measuring system noise floor to demonstrate it adequately, the DS2 notched spectrum performance remained unchanged, even at the maximum power setting of the Head End modem. This aspect addresses some speculation that intermodulation may occur within a PLT network and cause spectral re-growth within the notches.

Further work, to examine the practical benefits of the notching technique has been demonstrated in several simple examples where radio signals, previously buried under DS2 leakage emissions, were uncovered by notching.

DS2 were unable to apply notching in an upstream direction from either of the slave units. This is presumably because it would have conflicted with the dynamic power control of the slave units by the master units. It does, however, represent a significant shortcoming in the general concept of notching as an interference mitigation measure.

Launch power levels

DS2 stated that the PLT network at Ancaster Road was operating satisfactorily at a downstream launch power of -62dBm/Hz. This level was claimed to be sufficient to provide the advertised broadband service to S&SE's 6 customers, one as far as 230 metres from the launch point, without the use of intermediate repeaters.

Leakage emission levels

The leakage emission levels measured were as expected, having regard to the measurement position, distance from the source, power applied and the results of previous work.

There were two locations where it was possible to make a close approximation to a standard 3 metre regulatory measurement. At both of these, leakage emissions resulting from the Link 2 Home Gateway downstream spectrum, radiated by in-house wiring, were at levels close to the German NB30 radiated emission limit. (**Ref. 4**)

At one of these locations the Link 1Home Gateway upstream spectrum, also radiated by in-house wiring exceeded the German NB30 radiated emission limit by up to 15dB.

Section 4

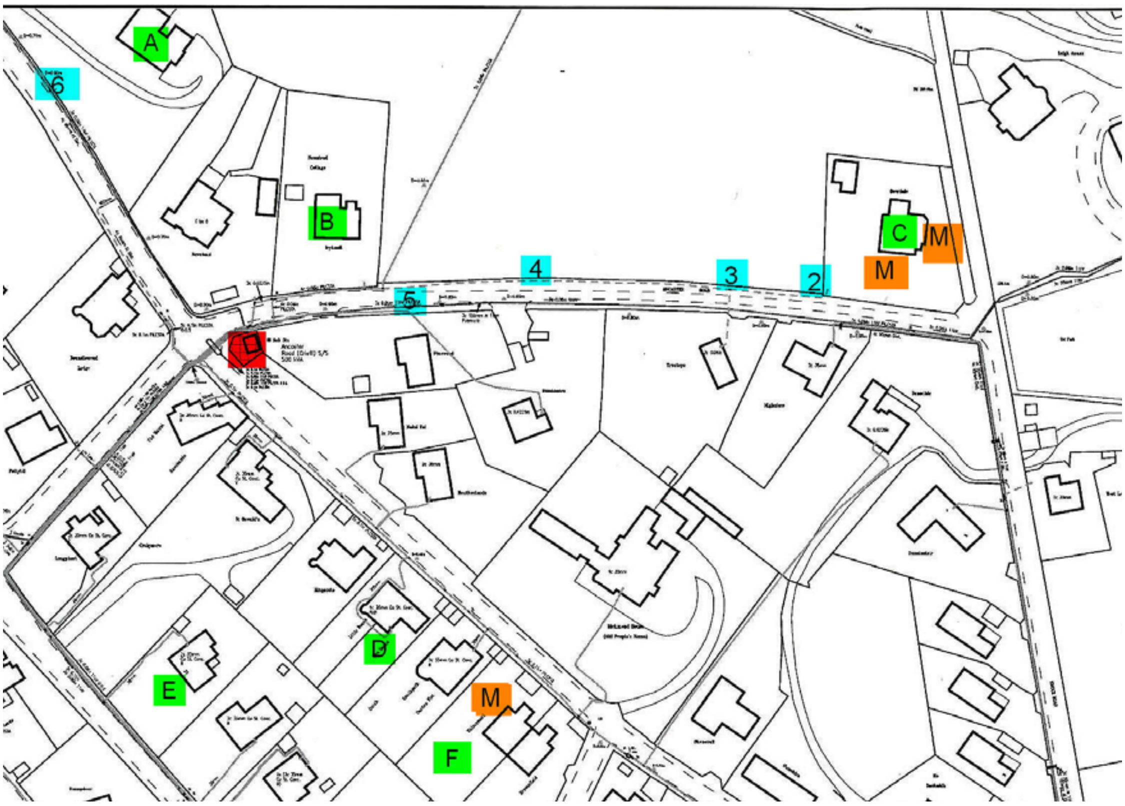
Test Notes

Measurement Location

At the time of testing, the Crieff DS2 deployment from Ancaster Road substation served 6 PLT customers, the most distant of which were over 200 metres from the substation.

The map below, provided by S&SE, shows that the area consists mainly of large residential properties arranged in a low density format.

Figure 1 Ancaster Road PLT Network



100 metres

Approximate Scale: ⟷

Key:

Red		**Ancaster Road electricity substation**
Green	**A, B, C, D, E, F**	**PLT Customer Premises**
Blue	**1, 2, 3, 4, 5, 6**	**Access network - measurement positions**
Orange	M	In-house network - measurement positions

The DS2 PLT system

DS2 based PLT equipment uses 1280 carrier OFDM signal architecture delivering a total data rate, per network, of 27 Mbps downstream and 18 Mbps upstream. Features of the system include fully programmable spectrum ranges operating between 1 and 38 MHz and a programmable transmission power mask to facilitate notching.
This and more information, can be found at: http://www.ds2.es/home/index_total.php

For network operators, a PLT management and monitoring solution, optimised for the DS2 product range, is available from Jeizer.™ This information, can be found at: http://www.jeizer.com/webjeizer/WEB_JEIZER/english/template_E.html

DS2 Network Architecture

Each DS2 PLT cell consists of two networks. The ‘access’ or outdoor part that comprises the LV 3 phase distribution network associated with a single electricity substation and the ‘in-house’ part that comprises the single phase internal electricity wiring in a PLT user’s premises. The networks, known as Link 1 and Link 2 are integrated to provide the end to end functionality of the product.

To provide full duplex operation, the substation to house ‘access’ spectrum (Link 1) is divided into upstream and downstream blocks. The Link 1 Head End master unit is situated in an electricity sub-station and communicates with the ‘slave’ units installed in PLT customer premises using the LV 3 phase distribution network as a transmission medium.

Except for PLT customers very close to the substation, where low attenuation renders this unnecessary, a similarly divided higher frequency spectrum is used for the ‘in-house’ network (Link 2) The transition between the Link 1 and Link 2 spectrum blocks is carried out by a Home Gateway unit located near the electricity meter in a PLT user premises. The Home Gateway unit acts as a slave for the Link 1 access network and a master for the Link 2 spectrum which uses the in-house electricity wiring as a transmission medium to carry PLT signals to and from a modem, normally situated by the user’s computer.

Crieff DS2 PLT Deployment

Link 1 (Access PLT Network)

Downstream (head end to home gateway)	7.8 to 11.3 MHz	Master	(768 carriers)
Upstream (home gateway to head end)	2.5 to 5.0 MHz	Slave	(512 carriers)

Link 2 (In-house PLT Network)

Downstream (home gateway to computer)	19.0 to 22.75 MHz	Master	(768 carriers)
Upstream (computer to home gateway)	13.8 to 16.3 MHz	Slave	(512 carriers)

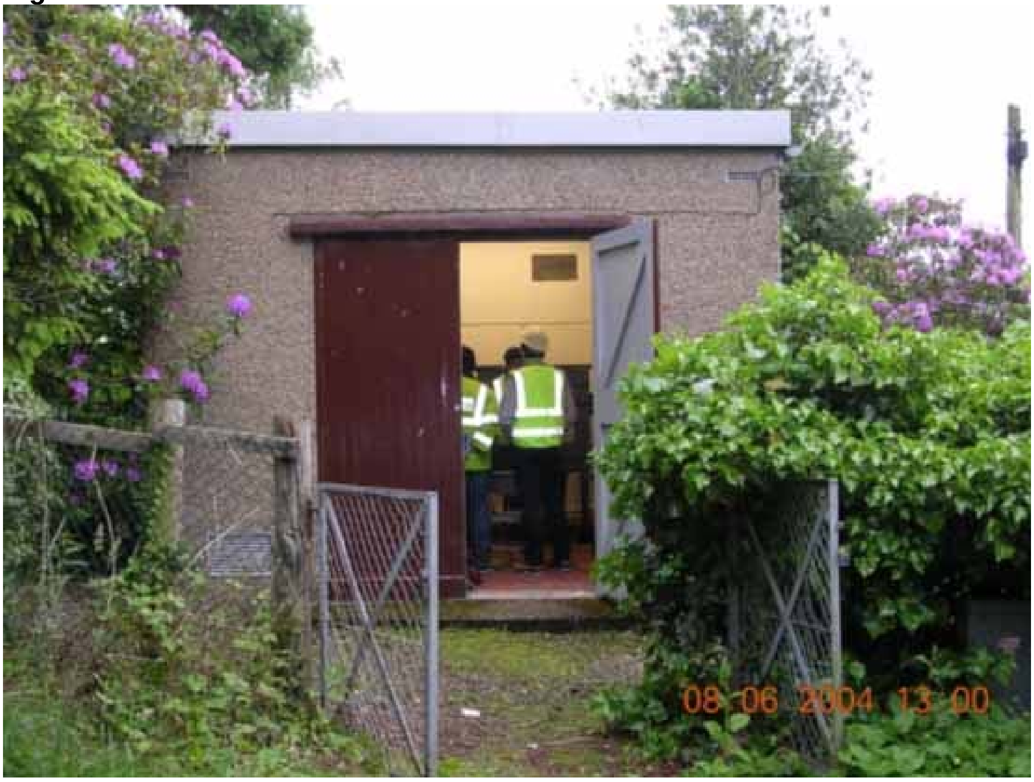
The downstream spectrum from both Link1 and Link 2 master units is continuous. The upstream spectrum from the slave units transmits only when allowed by the Head End master unit.

Transmit Power Spectral Density (PSD) can be varied in 6 dB steps, known as Levels. Level 1 represents the minimum value of -74dBm/Hz and Level 5 represents the maximum value of -50dBm/Hz. The power of the slave units is under dynamic control of the Master units in order to achieve a satisfactory signal to noise ratio.

The Ancaster Rd PLT enabled substation

At the time of testing, this PLT enabled 500 kVA substation supplied approximately 6 PLT customers with symmetrical broadband connections of up to 1Mbit/s using a Head End modem fitted with the DS2 chipset that is based on OFDM signal architecture.

Figure 2 Ancaster Road Sub-Station



The underground LV electricity distributors, carrying the PLT signals, exit the sub-station close to the lower ventilation grille shown on the left hand side of the picture.

PLT backhaul is provided by an overhead SDSL feed from the telegraph pole on the right hand side of the picture.

A small programme of conducted measurements was made inside the sub-station and the initial radiated measurements were made just outside it.

Test Equipment

Some conducted current measurements inside the substation were made with a Schaffner SMZ11 current clamp and a Rohde & Schwarz FSU3 spectrum analyser. All other measurements were made with a Rohde & Schwarz ESCS30 EMI measuring receiver.

Except where stated in section 5, all the radiated leakage emission measurements were made using a Rohde & Schwarz HM525, low noise, magnetic loop antenna. Both the antenna and the measuring receiver were battery powered to allow portability and to eliminate the possibility of ground loop currents adversely affecting the measurements. With the 9 kHz bandwidth and peak detector settings used, the magnetic field measuring system had a noise floor of approximately 10dBµV/m. This is up to 20 dB lower than can usually be achieved with measuring systems employing the standard 60cm loop antenna specified in CISPR 16.

DS2 & S&SE support during the measurements

Engineering representatives from both DS2 and S&SE were present throughout the test period to adjust the network settings, implement spectrum notches, to liaise with PLT customers and to witness the measurement processes.

Downstream Power Settings for the Access Network

It was emphasised by DS2 that a significant feature of their PLT product was its ability to function at a low signal to noise ratio allowing the use of a PSD of -62dBm/Hz at Crieff.

DS2 representatives were resistant to the idea that the PLT network should be tested at its full power settings in case the lower PSD benefits of the DS2 equipment were not clearly evident in this report. It was agreed that, in accordance with normal practice, the power setting in use would be recorded and shown in the results but that the full power capabilities of the product would be clearly indicated in this report.

It some instances it was necessary to operate the downstream access network at its full power setting of -50dBm/Hz in order to properly demonstrate the notching capabilities of the product but for most other measurements a power setting of -62dBm/Hz was used.

Leakage Emission Measurements from In-house Networks

It was DS2’s stated view that initial proposals to make leakage emission measurements inside a PLT user premises were unfair to their product as they could not be expected to ‘protect’ the reception of radio broadcasts in that environment.

It was argued by Ofcom that, in-house PLT leakage emissions are a potentially problematic issue both within multiple occupancy premises housing a PLT user and for premises immediately adjoining a PLT user. It was further argued that information about the level and extent of these emissions was important and would be required before decisions about emission limits could be made.

All parties to these measurements were, however, appreciative of the degree of customer premises access, already negotiated on our behalf by S&SE. In order to minimise further disruption and inconvenience to those customers it was agreed that measurements would be made at 1 & 3 metres from the outside walls of those premises but where possible, adjacent to the rooms containing PLT equipment.

Section 5

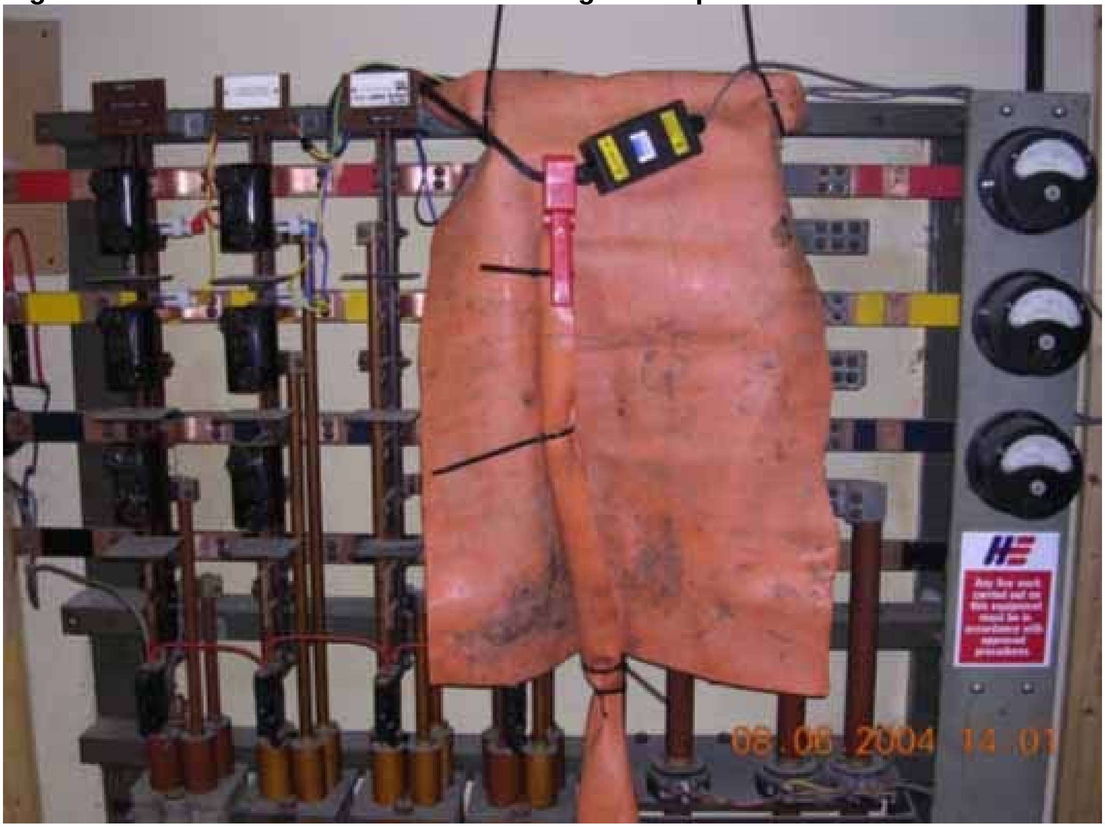
Measurement results

DS2 Link 1 Conducted Downstream Spectrum

The Head End downstream access spectrum was plotted at Ancaster Road substation.

The spectrum was characterised by measuring the common mode current on the cables joining the PLT couplers to the substation LV bus bars as shown below.

Figure 3 Substation Bus Bars with PLT signal coupler.



Coupling
S&SE apply PLT signals to the bus bars using the black coupler shown at the top middle of the picture. Coupling is symmetrical between the Red and Yellow phases with no neutral connection.

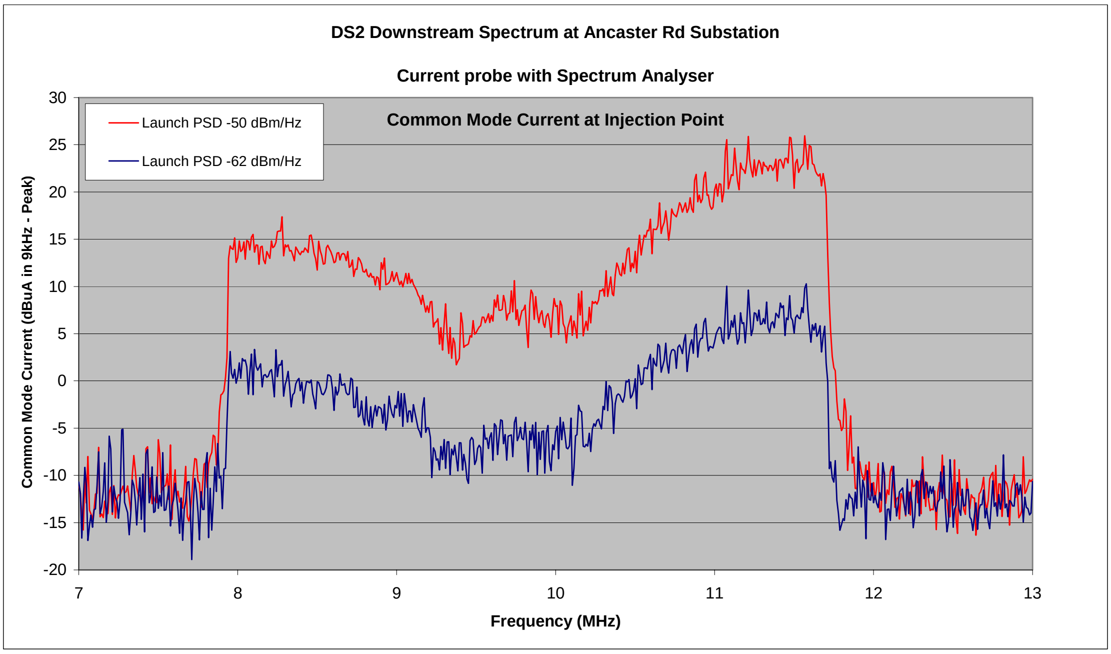
Measurements
A Schaffner SMZ11 current clamp is shown on the bus bar side of the PLC coupler. The measurement was of common mode current injected directly into the network.

Safety Note
As these measurements were made on the live electricity network, the current clamp was installed by qualified S&SE staff. A rubber insulation blanket and shrouding for the current clamp feeder cable can be seen in the photograph.

DS2 Conducted Downstream Spectrum – Spectrum Analyser Measurements

The charts that follow show the result of swept frequency measurements across the DS2 downstream access spectrum using a Rohde & Schwarz FSU3 Spectrum Analyser.

Figure 4 DS2 Conducted Downstream Spectrum – Power Settings



The chart shows the 7.8 to 11.3 MHz downstream spectrum used to transfer data from the substation to the home gateway units over the access part of the PLT network.

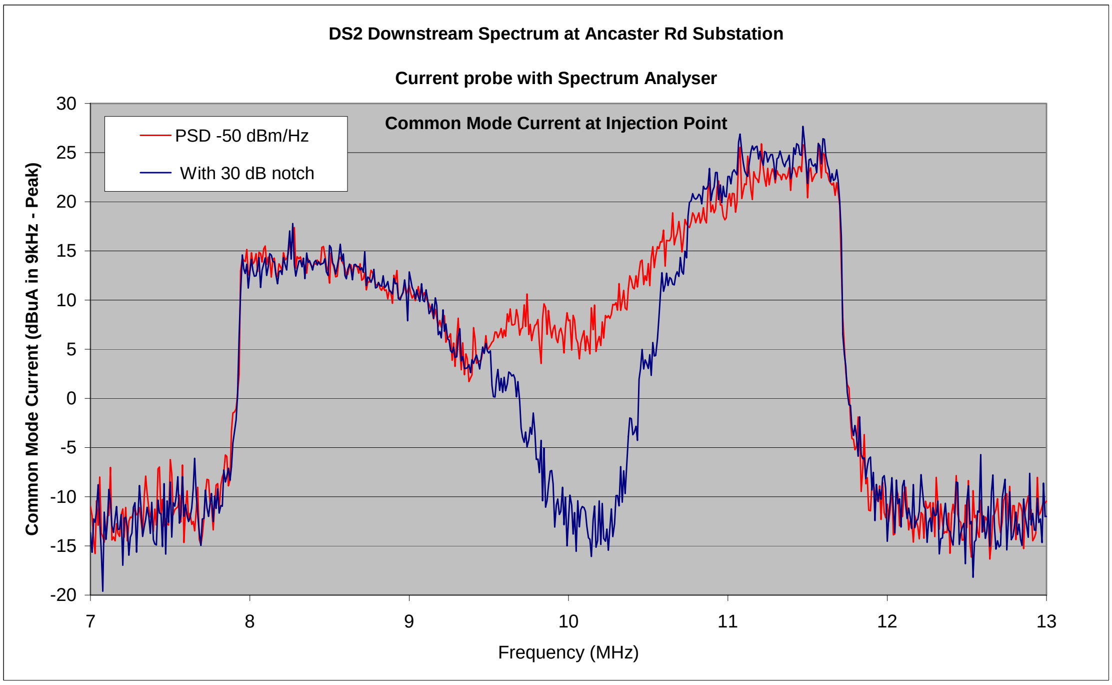
Both the ‘normal’ and the full power condition have been shown.

It can be seen that, unlike some first generation PLT equipment, the spectrum envelope has an extremely sharp roll-off at both sides of the operating band.

The shape of the amplitude curve is the result of variations in the common mode impedance of the electricity network and the frequency response of the PLT coupler.

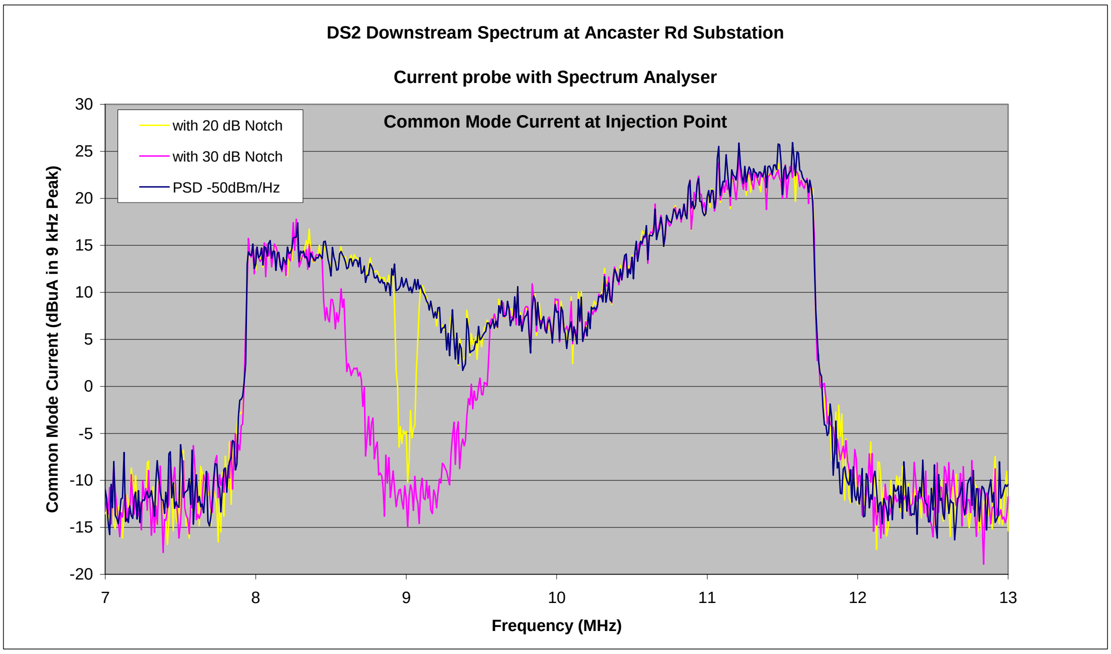
If it had been possible to make the measurements with the Head End unit connected to a constant impedance wideband load, then the in-band amplitude level would have been flat on the assumption that all carriers were being transmitted at the same power.

Figure 5 DS2 Conducted Downstream Spectrum – with notch at 10.125 MHz



The chart shows a ‘30dB’ notch centred on the 10.1 to 10.15 MHz Amateur Radio Band

Figure 6 DS2 Conducted Downstream Spectrum – with notch at 9 MHz

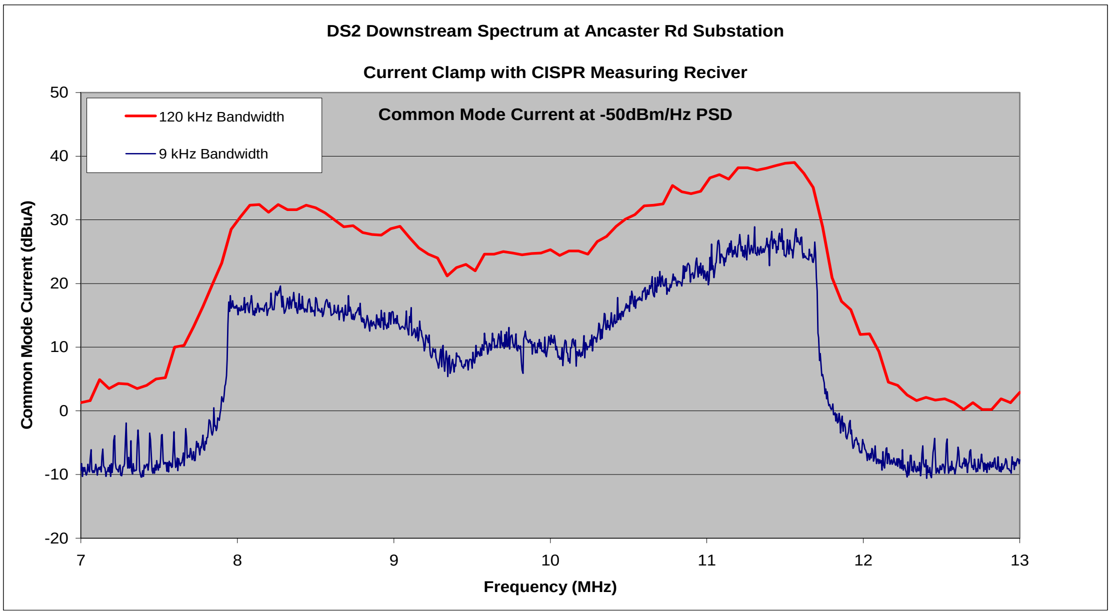


The plot shows a, sharp sided, 20 dB deep notch applied between 8.965 & 9.040 MHz by DS2 engineers.

Also shown, is a 30 dB deep notch specified for the same frequencies. As can be seen the extra 10dB notch depth has resulted in a substantial loss of wanted bandwidth.

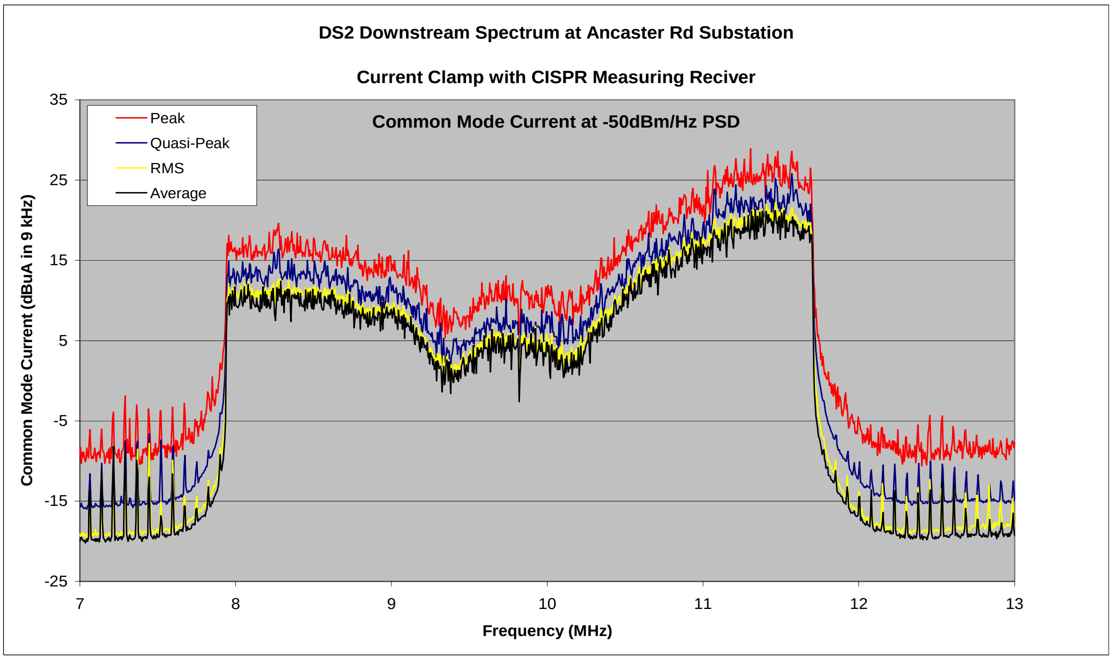
DS2 Downstream Spectrum – ESCS30 Measuring Receiver Responses

Figure 7 Measuring Receiver Bandwidth Response to DS2 signal



It can be seen that the difference in peak level is approximately 11dB [10 log (120k/9k)] indicating the noise like structure of the DS2 OFDM signal.

Figure 8 Measuring Receiver Detector Response to DS2 signal



Taking the Peak Detector reading as a reference, the approximate response of the receiver’s detectors to the DS2 OFDM signal is:

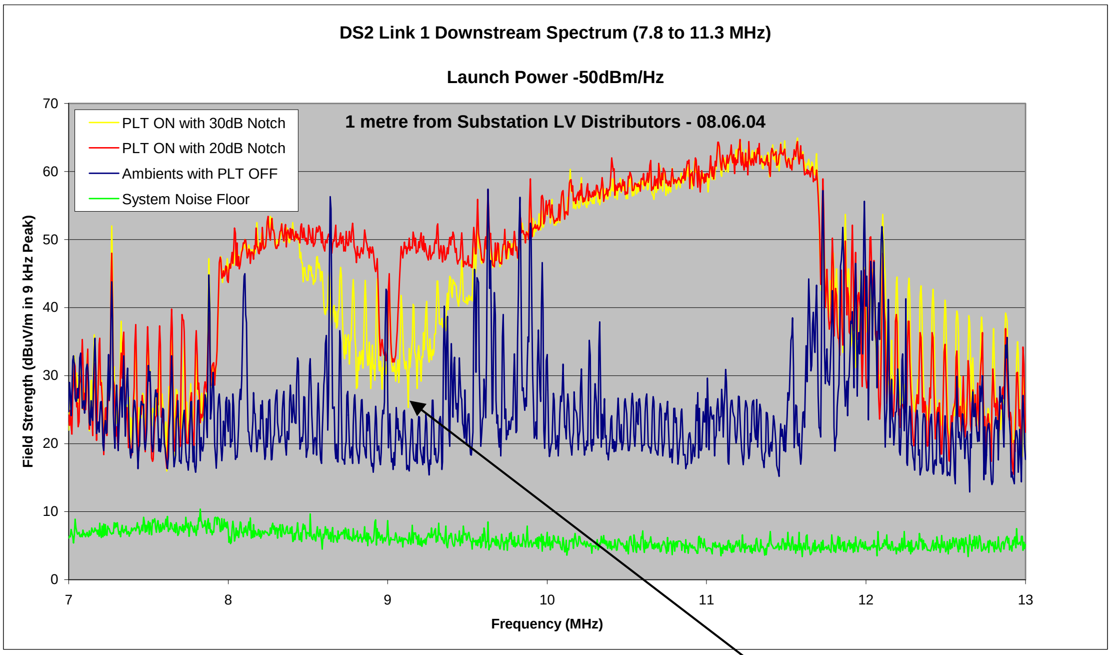
Quasi-peak	-3 dB
RMS	-5 dB
Average	-6 dB

Radiated Emission Measurements in Ancaster Road

The chart below shows a ‘worst case’ radiated emission level measurement made at approximately 1 metre from the underground LV distributors leaving the Ancaster Rd substation.

The measurement was made with a Rohde & Schwarz HM525 loop antenna and ESCS30 measuring receiver.

Figure 9 Leakage Emissions outside Ancaster Rd Sub-Station (location 1)



The plot shows notches between 8.965 & 9.040 MHz.

Both 20 dB and 30 dB notches were individually applied and the effect of these can be seen.

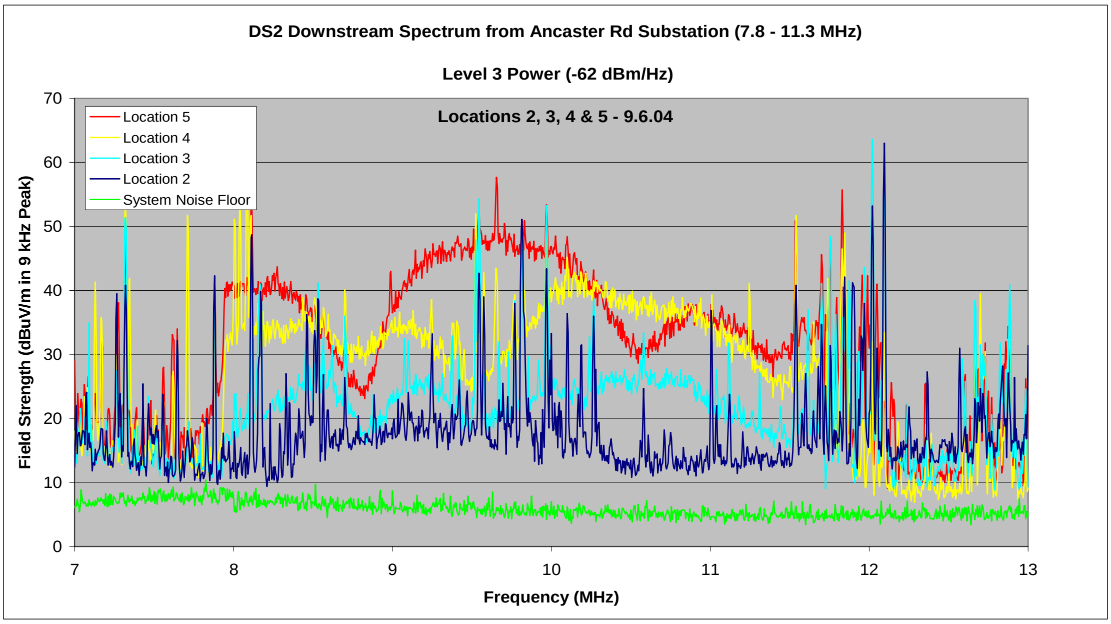
It appears that the 30dB notch is not significantly deeper than the 20dB notch, but the chart shows noise spikes both within the 30 dB notch and at either side of the DS2 downstream spectrum block. These spikes were found to be coming from the switch mode power supply unit in the DS2 modem and have led to a false impression about the depth of the 30dB notch.

It can also be seen that some lower level spikes, of unknown origin, were evident in the ‘PLT OFF’ plot when the DS2 Modem was not operating.

Downstream Leakage Emission Measurements in Ancaster Road

Measurements at positions 2 to 5 along Ancaster Road have been grouped together to provide a quick overview of the leakage emission situation. Photographs of these measuring locations appear in **Annex B**

Figure 10 DS2 Downstream Spectrum leakage in Ancaster Road



The leakage emissions shown are due to the DS2 access PLT spectrum transmitted from the Head End unit in Ancaster Road substation.

The measurements were made with the loop antenna placed directly over the underground cables supplying electricity to the houses shown in the table below. The positions used were close to where the single phase house supply feeders were jointed to the main underground 3 phase LV distributor running along Ancaster Road.

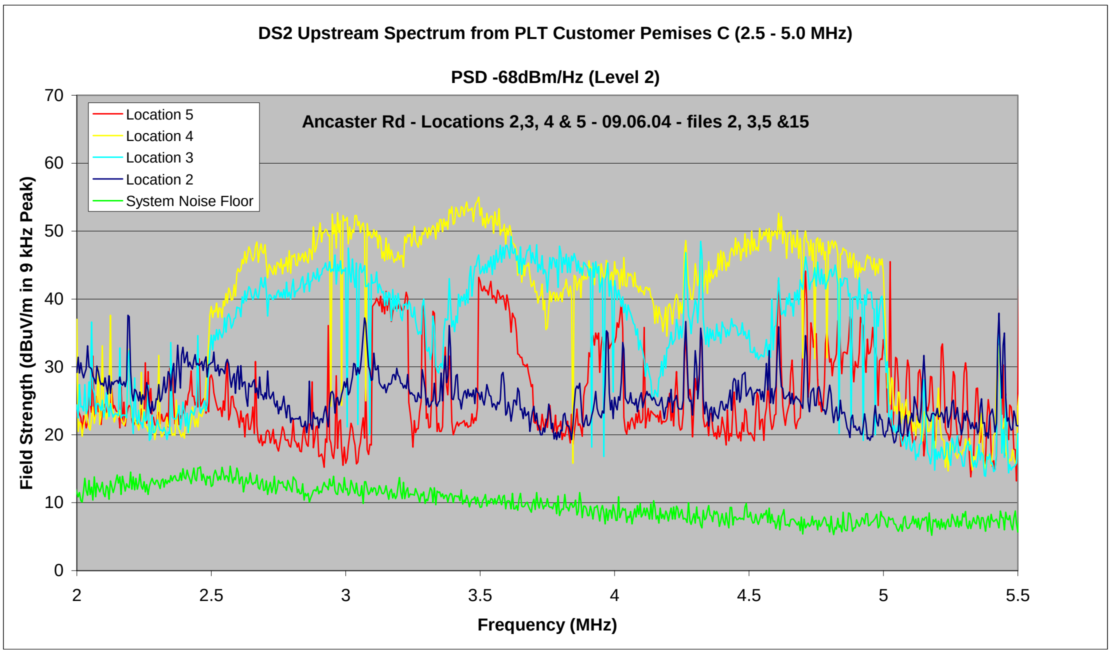
Figure 11 Ancaster Road Measurement Locations – Table 1

Map Location Number	Description	PLT Customer Premises	Approximate cable distance from substation injection point
2	Outside ‘Overdale’	Yes **(see note)**	190 metres
3	Outside ‘Treetops’	No	160 metres
4	Outside ‘Rumbleden’	No	110 metres
5	Outside ‘Pinewood’	No	55 metres

Note: *Overdale was at the end of the Ancaster Road LV distributor and had a 3 phase supply. It was unclear whether there was any separate joint underneath the measuring position, at the external boundary of the property, or whether the 3 phase LV distributor ran in a continuous length up to the house.*

The results show that, as expected, the leakage emissions radiated from the cables generally decrease in level as the distance from the substation is increased.

Figure 12 Upstream Spectrum



The leakage emissions shown above are due to the DS2 upstream access spectrum transmitted from the Home Gateway slave unit in ‘Overdale’ at the far end of the Ancaster Road section of the PLT network.

In order to produce a continuous spectrum, the Home Gateway unit was exercised by DS2 engineers to produce a data transfer rate of 800kb/sec. The upstream PSD of all Home Gateway units is automatically controlled by the head-end master unit with the setting used in this case being shown in the chart above.

Figure 13 Ancaster Road Measurement Locations – Table 2

Location Number	**Description**	**PLT Customer Premises**	**Approximate cable length to nearest PLT customer Home Gateway unit**
2	Outside ‘Overdale’	Yes **(see note)**	30 metres
3	Outside ‘Treetops’	No	60 metres
4	Outside ‘Rumbleden’	No	110 metres
5	Outside ‘Pinewood’	No	100 metres

Note: Overdale was at the end of the Ancaster Road LV distributor and had a 3 phase supply. It was unclear whether there was any separate joint underneath the measuring position, at the external boundary of the property, or whether the 3 phase LV distributor ran in a continuous length up to the house.

The upstream levels at position 2 were much lower than expected. This is likely to have been due to the beneficial effect of PLT signal balance within the 3 phase feeder to the house and possibly also to the absence of a joint at the measurement position.

5.3 Notched Spectrum Measurements in Ancaster Road

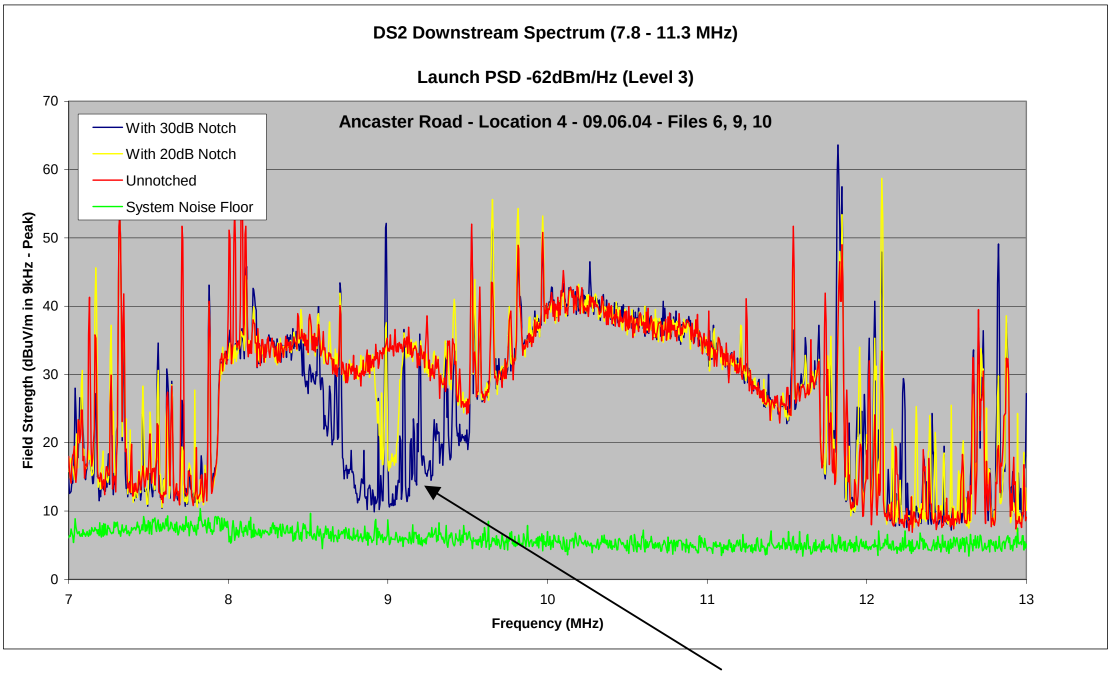
Radiated emission measurements of notched DS2 downstream spectrum were made at location 4, about halfway from the substation to the furthest point of the Ancaster Road PLT network.

All notches were applied directly by DS2 engineers at the Ancaster Road substation rather than remotely by S&SE, using the management software available to them at their PLT control centre in Perth.

The equipment has downstream notching capabilities within both the access spectrum from the Head End unit and the in-house spectrum from the Home Gateway units installed in each customer premises.

Notching is not supported in the upstream spectrum.

Figure 14 DS2 Downstream Spectrum with notch between 8.965 and 9.040 MHz

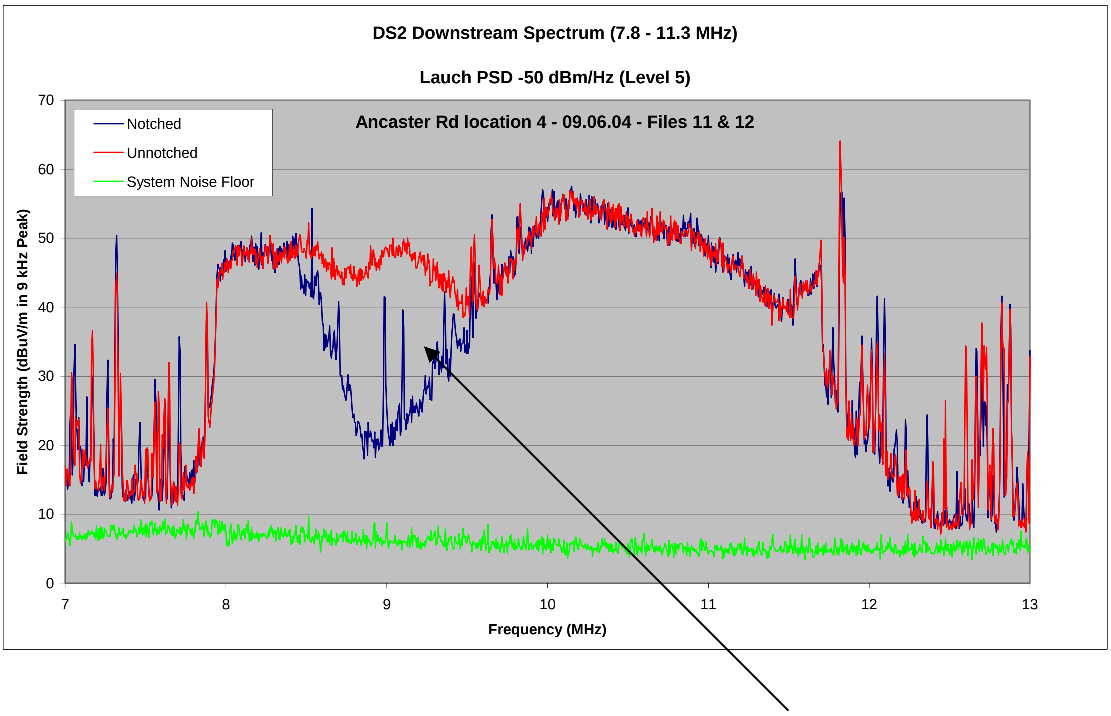


Notched Spectrum

In this part of the DS2 spectrum the unnotched level was only 25dB above the ambient noise floor. In order to display the full 30dB notch depth an increase in launch power was required.

For this measurement the Head End unit in Ancaster Road substation was set to maximum power in order to generate a sufficient level of leakage emissions to demonstrate the full performance of the notching technique.

Figure 15 Downstream Spectrum with 30 dB notch between 8.965 and 9.040 MHz



Radio transmissions ‘uncovered’ by the notch

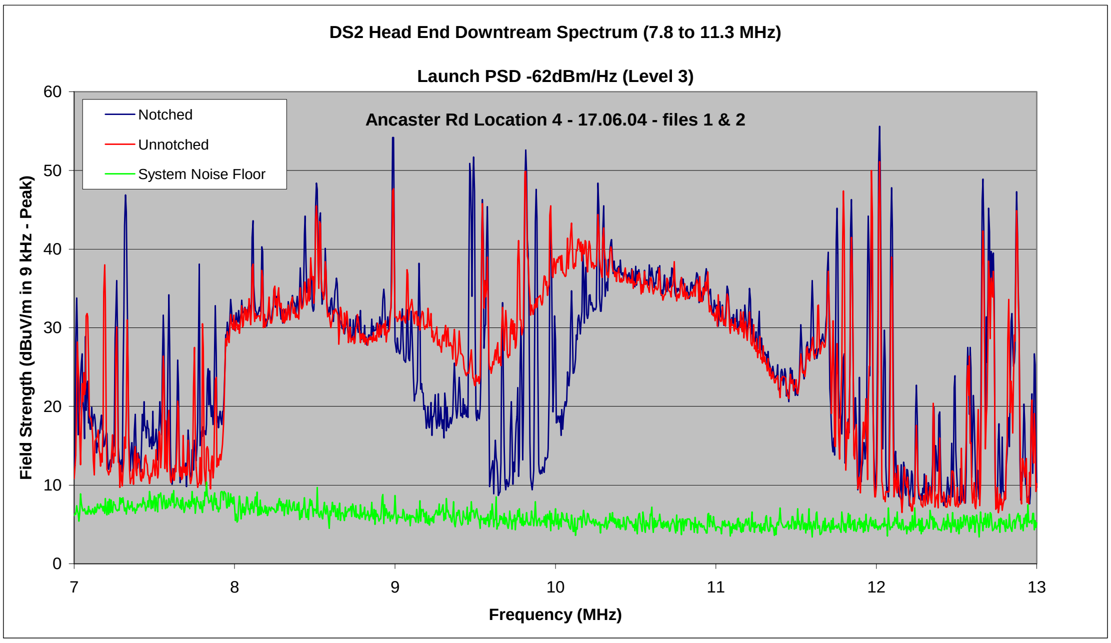
The chart shows the DS2 downstream access spectrum with the deepest notch that can be applied.

It can be seen that the notch was effective in uncovering, part of, two radio transmissions that would otherwise have been completely buried beneath the PLT signal.

A point to note is the substantial loss of downstream bandwidth that has occurred despite the 30 dB notch requested being only 75 kHz wide.

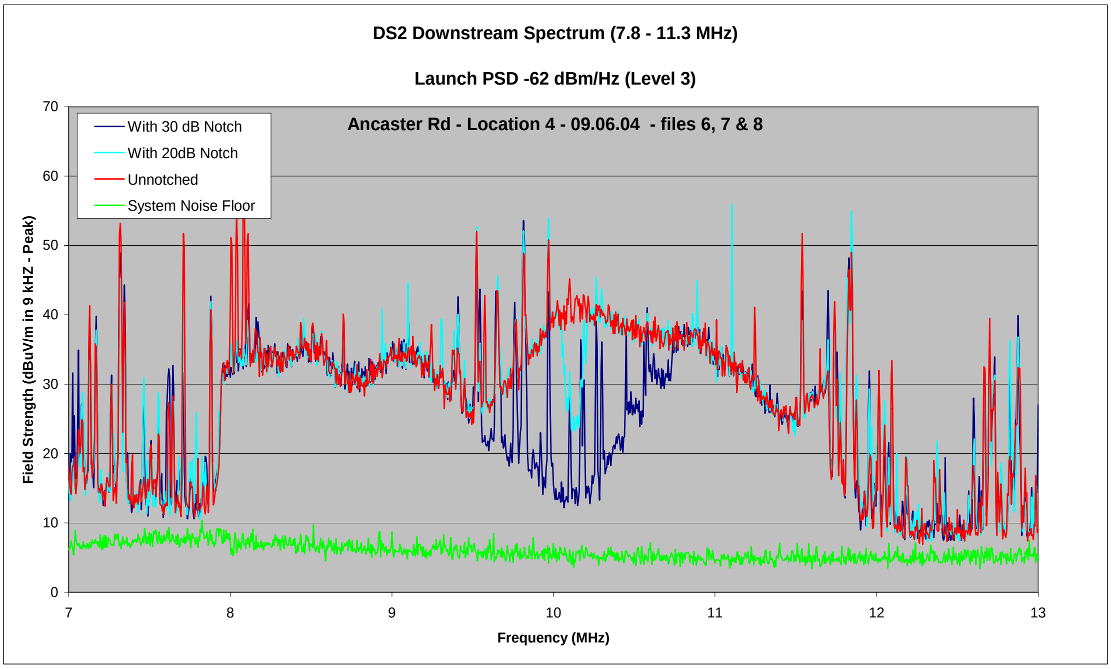
Further notches within this spectrum block were examined and these are shown overleaf.

Figure 16 Downstream Spectrum with 30 dB notch between 9.4 and 9.9 MHz



This notch covers the 9.4 to 9.9 MHz broadcast band.

Figure 17 DS2 Downstream Spectrum with notches between 10.10 and 10.15 MHz



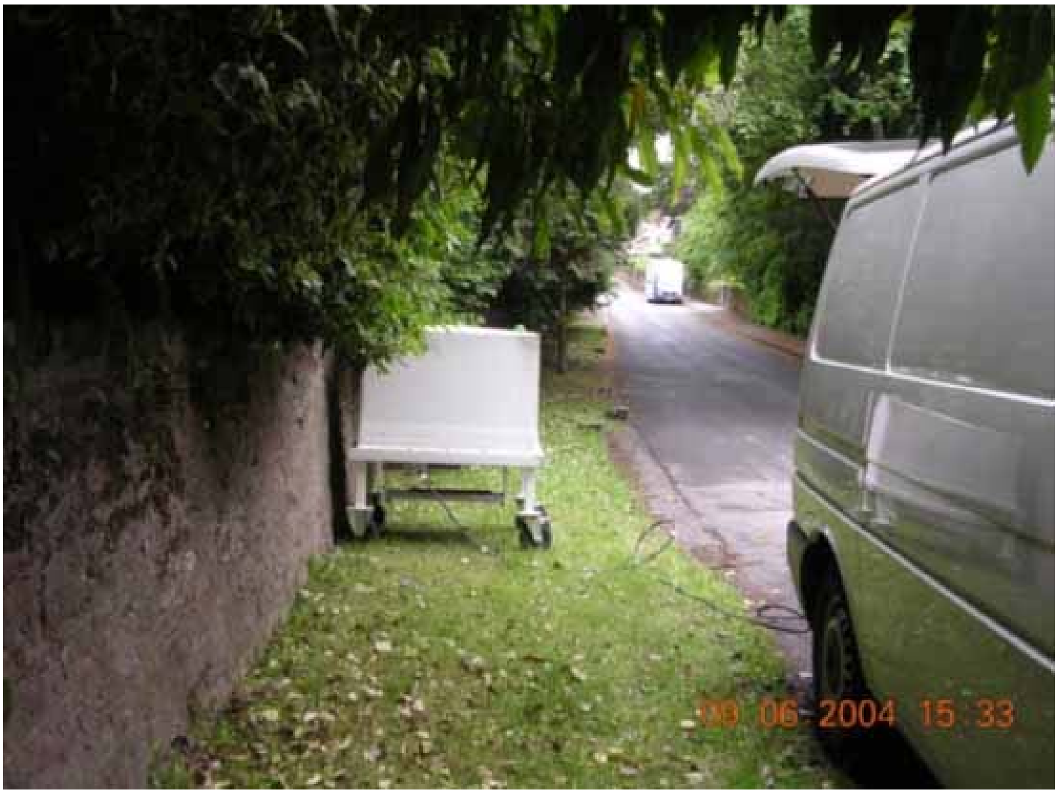
These notches were specified to cover the 10.1 to 10.15 MHz Amateur Radio band.

The notch bandwidth specified was the same in both cases. There was insufficient launch power to demonstrate the full depth of the 30dB notch as a radiated measurement at this location.

Leakage Emission Measurements in Drummond Terrace

This measurement location was chosen to supplement the Ancaster Rd leakage emission measurements because it was outside a PLT customer premises that had a conventional single phase supply rather than the PLT customer in Ancaster Road (location 2) that had a 3 phase supply.

Figure 18 Location 6 – Outside PLT Customer Premises A (Tom an Oir)



The location shown is a grass verge outside the boundary wall of PLT customer premises A.

The Rohde & Schwarz HM525 loop antenna (**see note**) can be seen in position over the underground single phase electricity feeder where it enters the grounds of the premises.

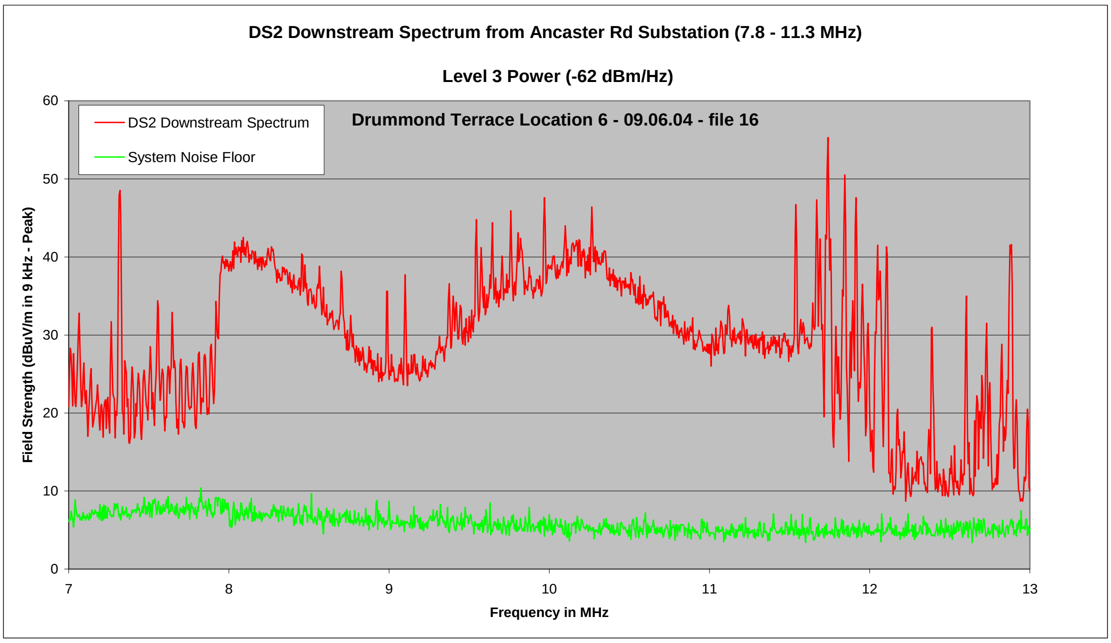
The distance to Ancaster Rd substation injection point is approximately 100 metres

The distance to the customer premises is approximately 30 metres

Measurement distance from antenna to the underground LV feeder is between 1 & 2 metres.

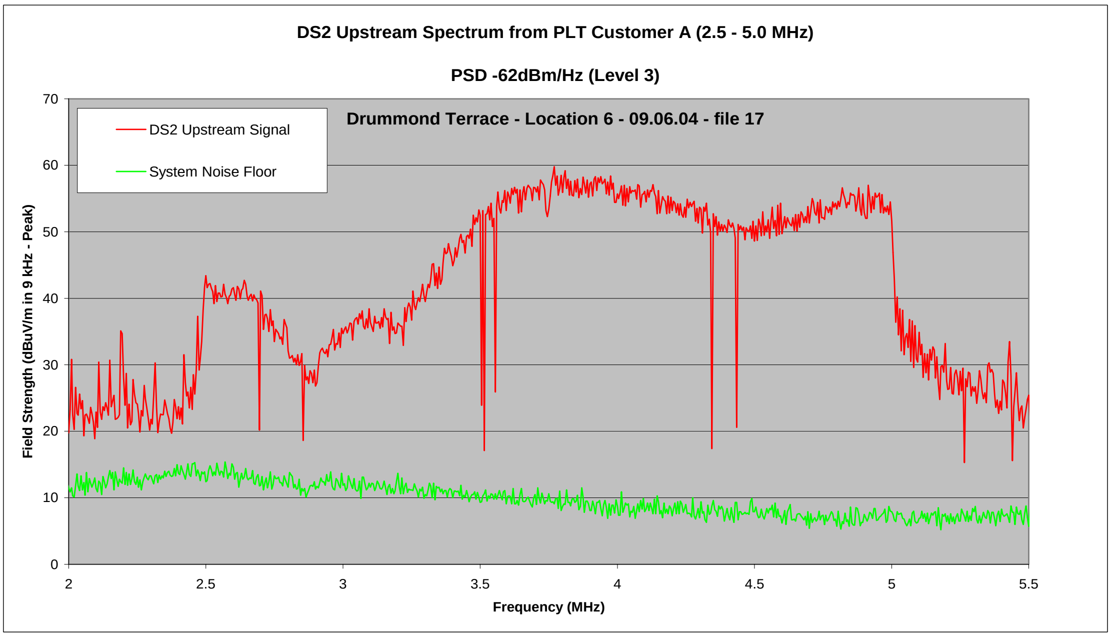
Note:
The Rohde & Schwarz HM525 low noise loop antenna is designed for laboratory use but has been housed in a weatherproof fibreglass enclosure to facilitate external use.

Figure 19 Drummond Terrace - Location 6 – Link 1 Downstream Spectrum



These levels are consistent with those measured at location 4 in Ancaster Road, also approximately 100 metres from the substation and shown in Figure 10.

Figure 20 Drummond Terrace - Location 6 – Link 1 Upstream Spectrum



In order to produce the continuous upstream spectrum shown, the Home Gateway unit was exercised by DS2 engineers to produce a data transfer rate of 750kb/sec

Note the significant difference in the upstream leakage emissions from this customer's Home Gateway unit compared with that measured at location 2 in Ancaster Road which is shown in Figure 12.

The chart below shows the Link 2 downstream leakage emissions from the PLT customer's Home Gateway unit being 'conducted backwards' and radiated by the incoming single phase service cable.

Figure 21 Drummond Terrace Location 6 – Link 2 Downstream Spectrum

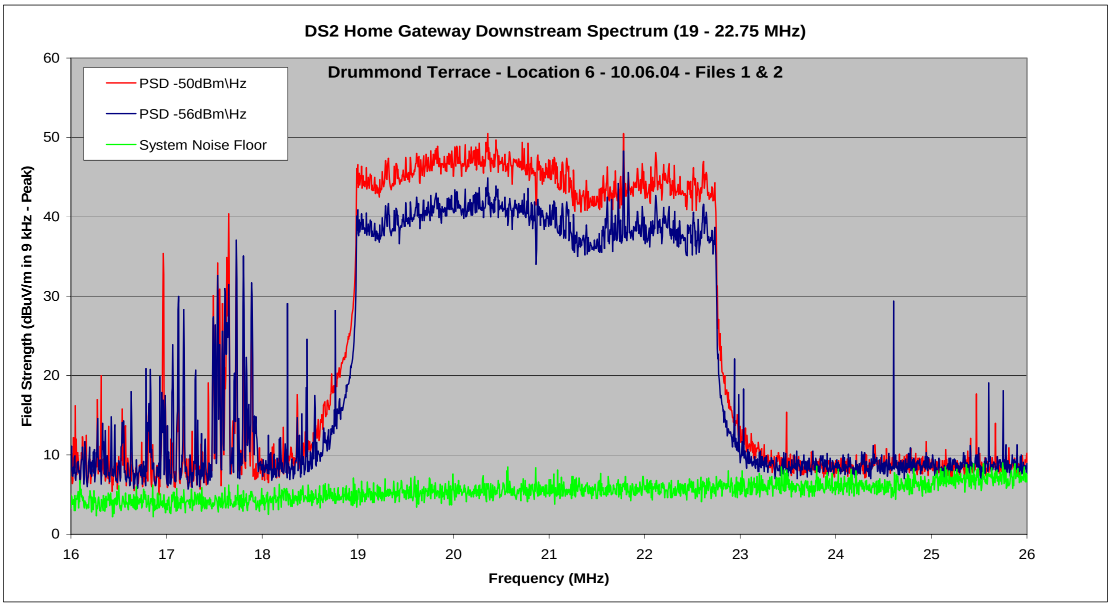
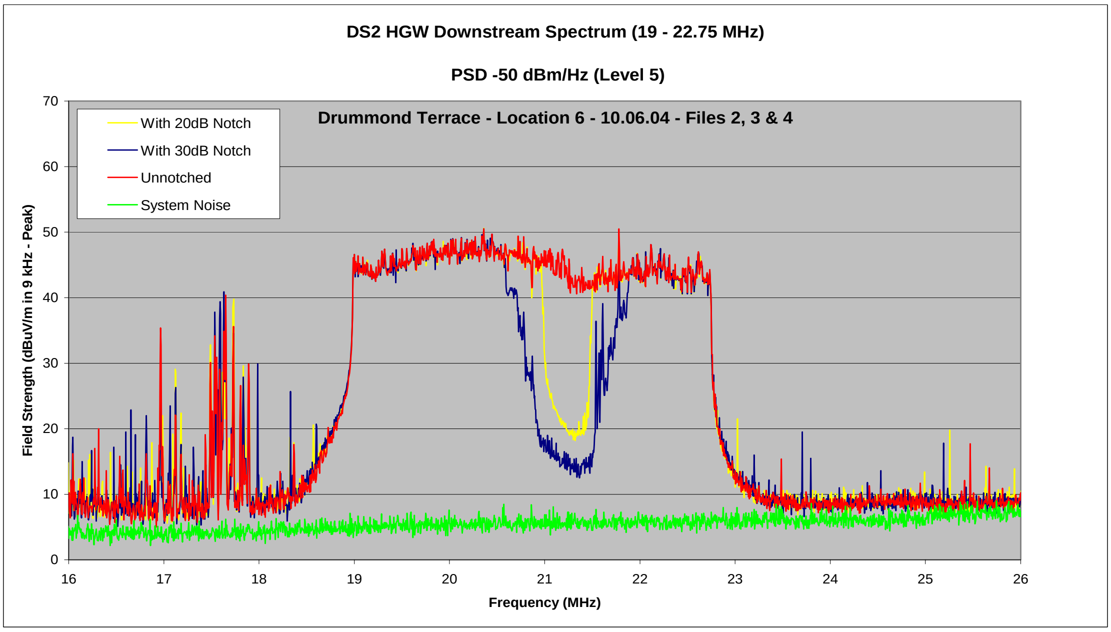


Figure 22 Link 2 Downstream Spectrum with notch between 21 & 21.45 MHz



This chart shows notches in the 21 to 21.45 MHz Amateur Radio band.

It can be seen that, in this instance, the 30dB notch has been implemented with less loss of wanted bandwidth than has occurred with other 30dB notches. The reason for this is unknown.

Notched Spectrum Measurements in Drummond Terrace

Figure 23 Link 1 Downstream Spectrum with notch between 9.4 & 9.9 MHz

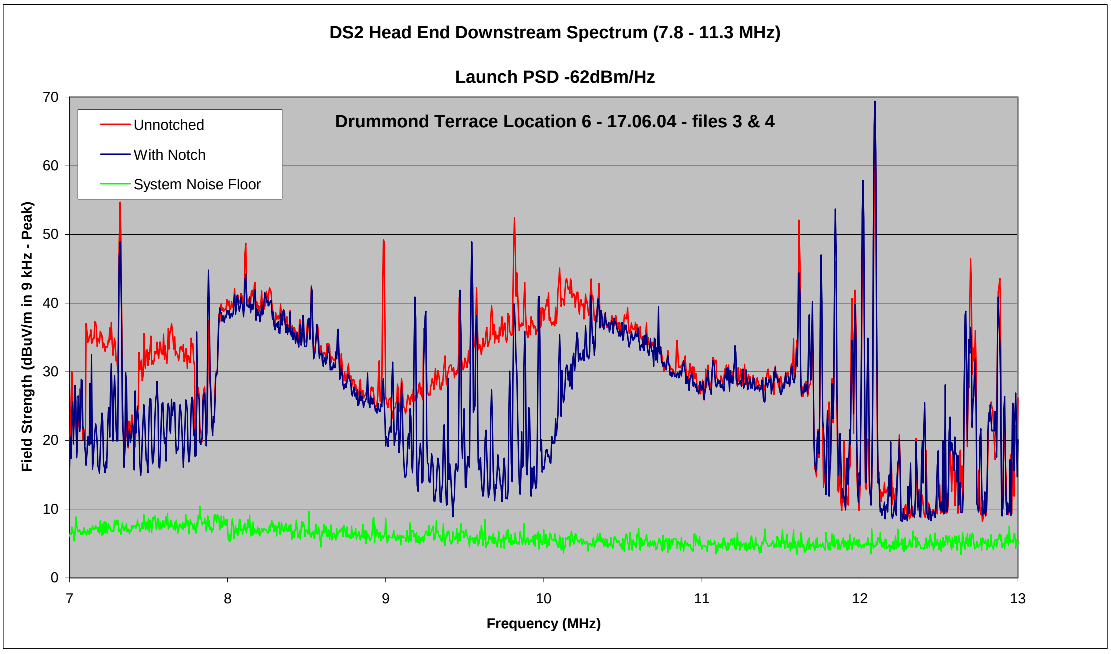
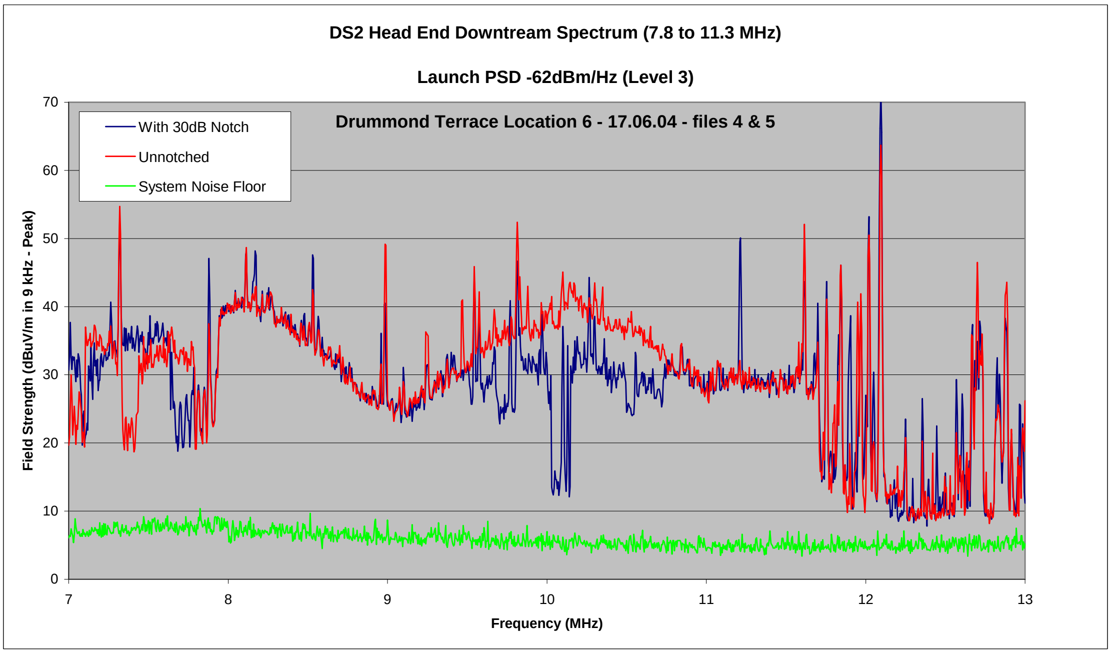


Figure 24 Link 1 Downstream Spectrum with notch between 10.1 & 10.15 MHz

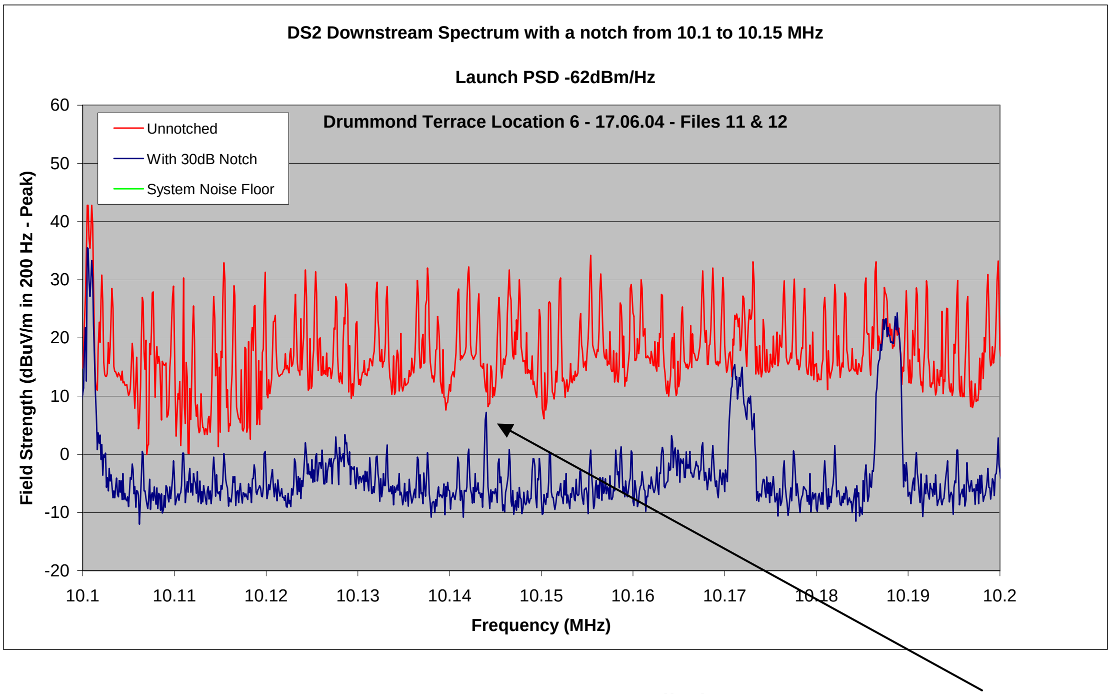


This chart shows the only sharp sided 30dB notch seen. The reason for the difference between this notch and other, much wider, 30dB notches is unknown.

To examine the effectiveness of notching on the reception of a weak signal, a high resolution frequency scan was made using a 200 Hz receiver bandwidth with 100 Hz frequency increments.

These measurements were made in the 10.1 to 10.15 MHz Amateur Radio band and the results are shown below.

Figure 25   Link 1 Downstream Spectrum with notch between 10.1 & 10.15 MHz



DK0WCY Amateur Radio beacon on 10.144 MHz

The top trace is the unnotched DS2 spectrum that shows OFDM carriers with 1.1 kHz spacing.

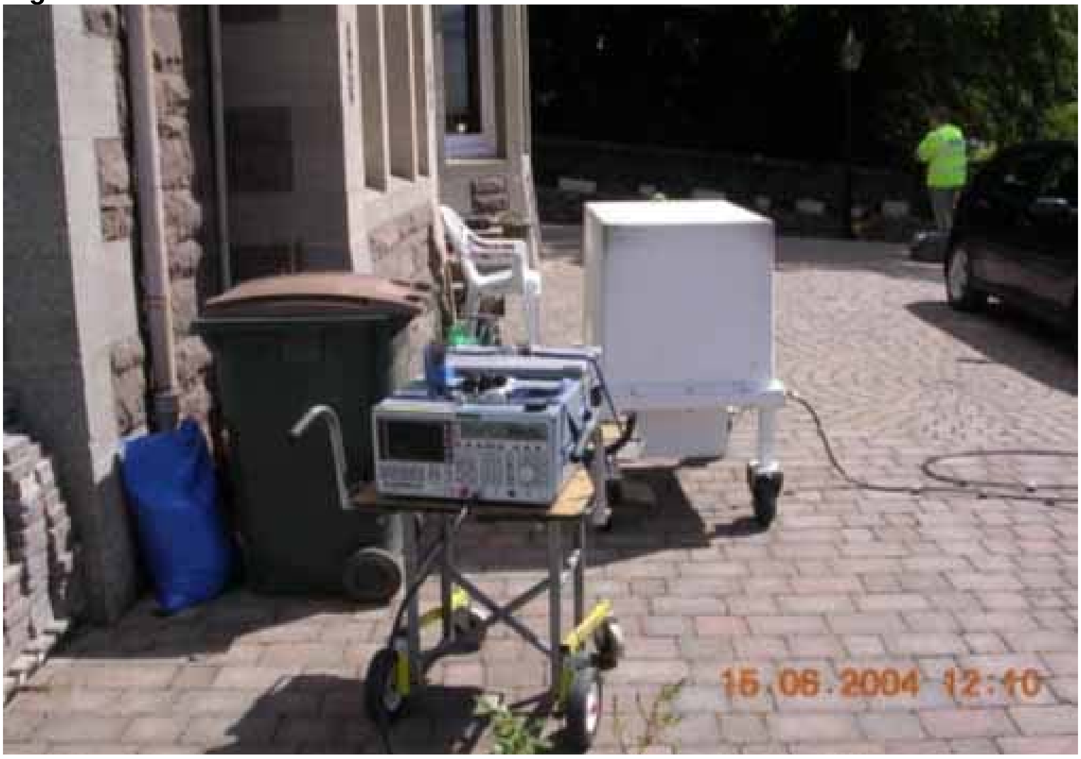
The lower trace shows the notched spectrum with the OFDM carriers reduced by 30dB.

Also shown within the notched spectrum, is the German Amateur Radio beacon DK0WCY being received at a level of 7dBµV/m. This beacon transmits its call sign identification in Morse code and this was clearly audible on the measuring receiver.

Leakage Emissions from PLT Customer Premises C

This House is located at the far end of the Ancaster Road section of the PLT network approximately 220 metres from the substation. The house has a 3 phase electricity supply to power an outside workshop. This is most unusual for domestic premises.

Figure 26 Ancaster Road PLT Customer Premises C – Position 1



The picture shows the battery powered measuring receiver and loop antenna in position 1, a location 1 metre from the wall of the house. Although not usually specified below 30 MHz, some Electric Field measurements were made at this house. There were several reasons for this initiative:

1.) There has been much speculation about the nature of PLT networks as radiating sources. In particular, whether magnetic or electric fields predominate at the sort of measurement distances usually specified in radiated emission standards.

2.) Broadcast reception in this frequency range usually involves the use of a portable receiver with a whip antenna responding predominantly to the electric field component of an electromagnetic wave. Should there prove to be any significant difference between the magnetic and electric fields radiated, then an electric field measurement would be more representative of the situation faced by a listener using such a receiver.

3.) Electric field measuring antennas, suitable for this frequency range, usually comprise a 1 metre rod mounted over a ground plane but this arrangement does not readily lend itself to changes of height and polarisation. More recently, a new design of electrically short active dipole antenna has become available. This antenna has a relatively low noise performance together with extremely compact dimensions. Such an antenna seemed ideal for this exercise, particularly for in-house measurements.

Leakage Emissions from PLT Customer Premises C – Position 1

The leakage emissions shown on this page are due to the upstream spectrum from the Home Gateway unit being radiated by the house wiring.

Figure 27 Link 1 Upstream - House C – Position 1 - Magnetic Field

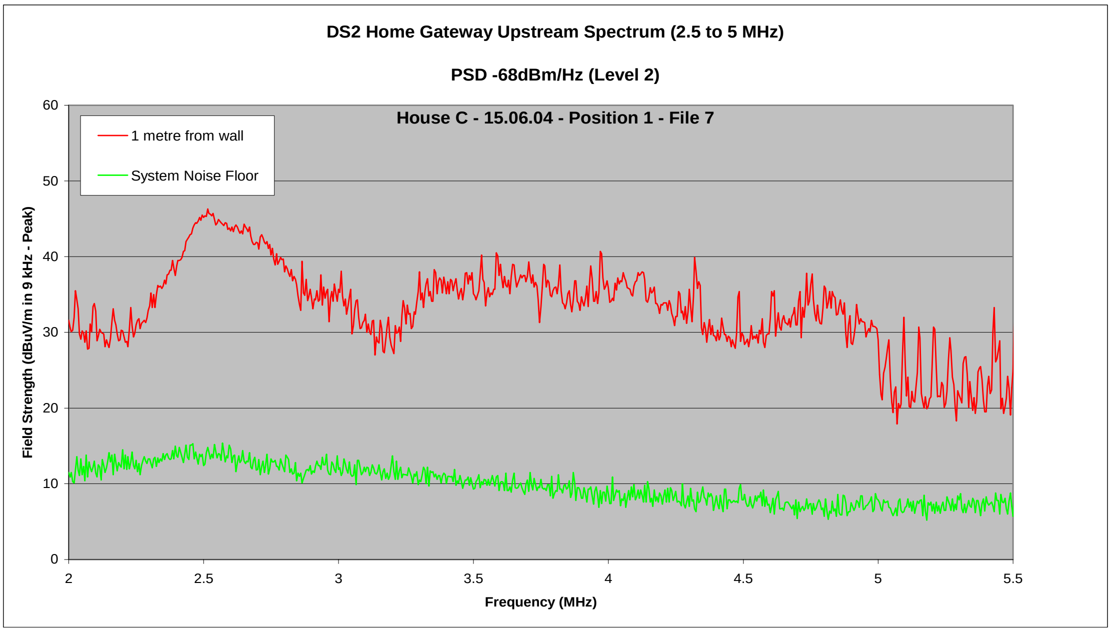
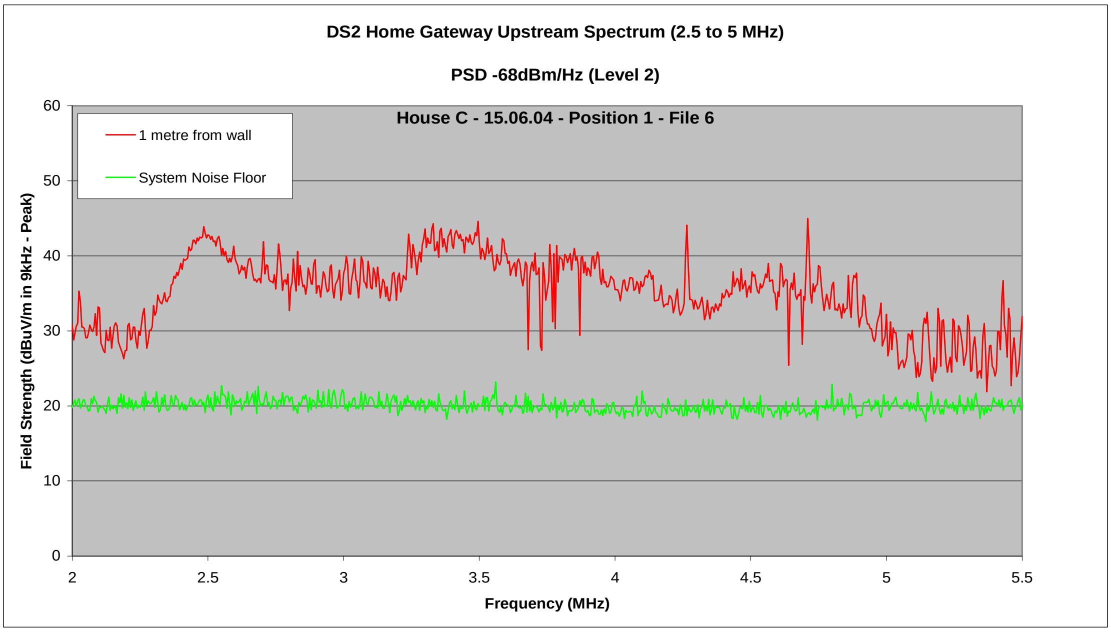


Figure 28 Link 1 Upstream - House C – Position 1 - Electric Field



Measured with a vertically polarised Schwarzbeck EFS 9219 short active dipole antenna mounted 2 metres above ground.

It can be seen that the magnetic and electric field measurements have shown very similar results.

The leakage emissions shown on this page are due to the downstream spectrum from the Home Gateway unit being radiated by the house wiring.

Figure 29 Link 2 Downstream - House C – Position 1 - Magnetic Field

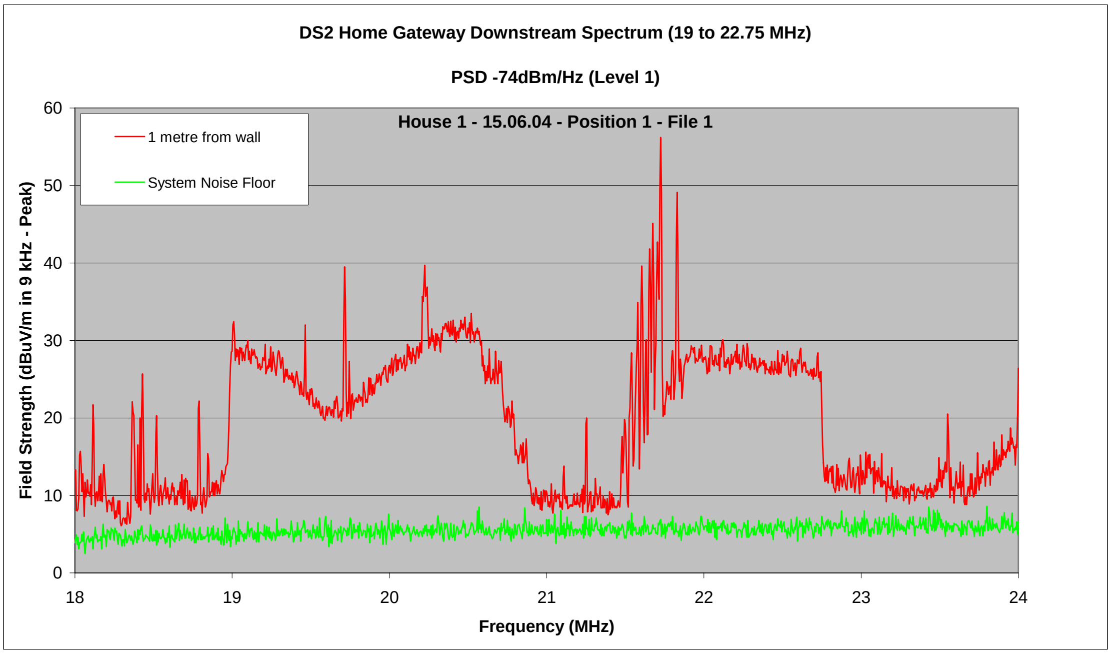
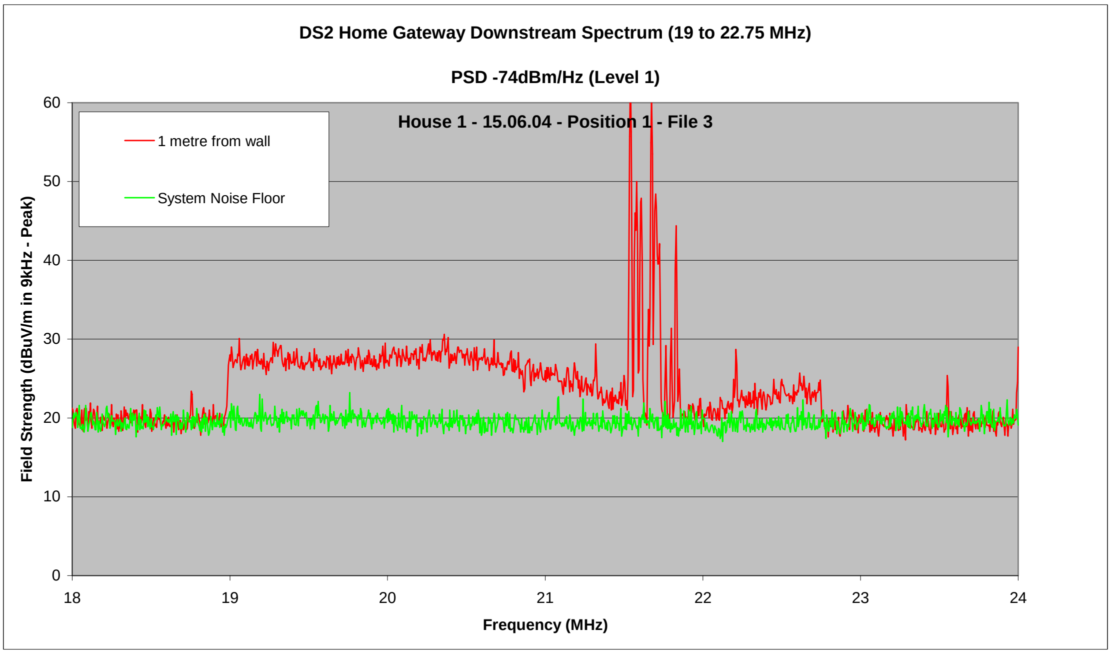


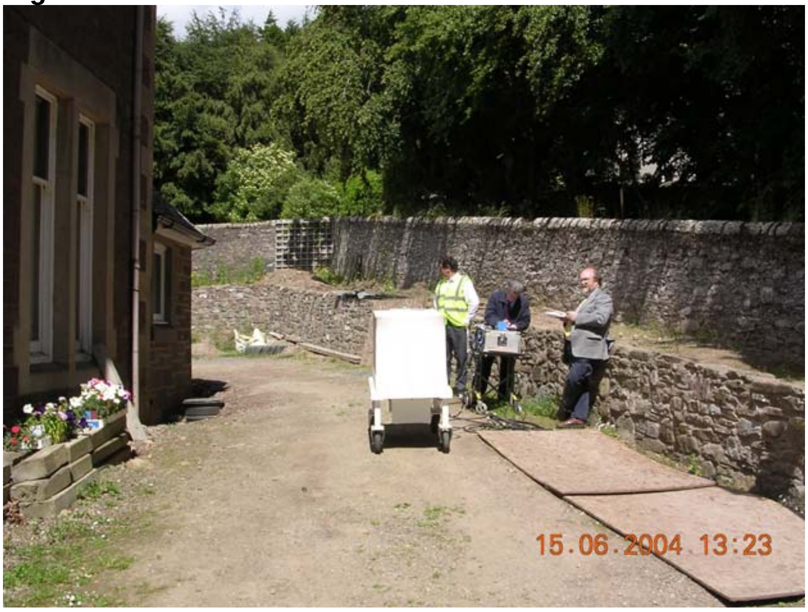
Figure 30 Link 2 Downstream - House C – Position 1 - Electric Field



Measured with a vertically polarised Schwarzbeck EFS 9219 short active dipole antenna mounted 2 metres above ground.

The second measurement position, shown below, was 3 metres outside the window of the room containing the customer's computer.

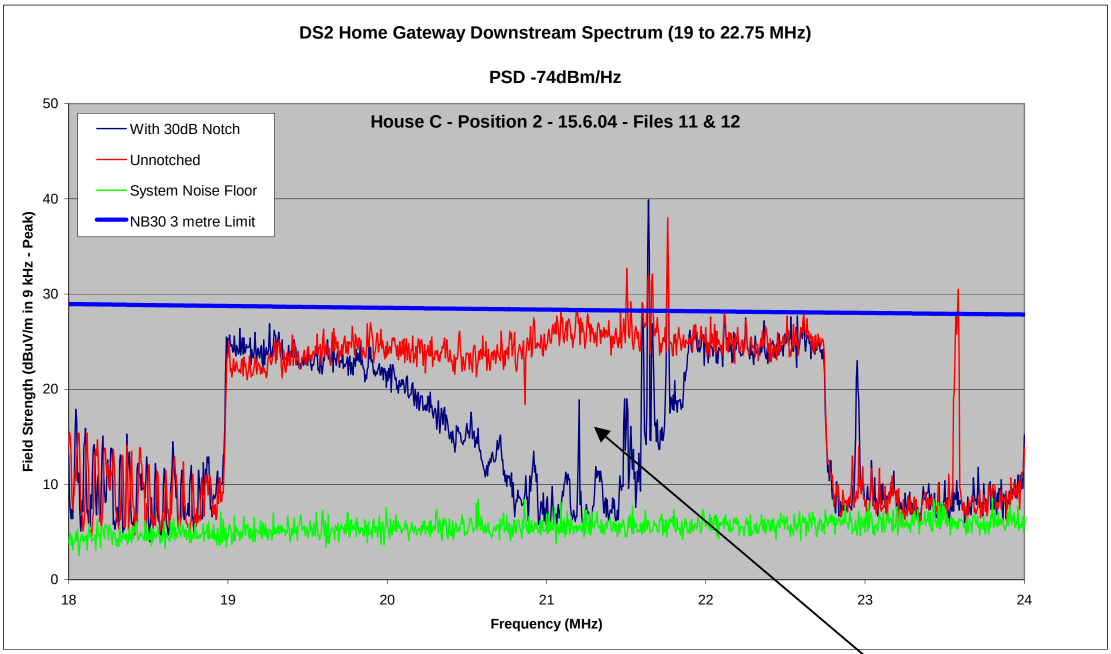
Figure 31 Ancaster Road PLT Customer Premises C – Position 2



Link 1 and Link 2 upstream measurements, were abandoned at this position due to intermittent emissions from an unidentified switch mode power supply unit located within the customer's premises.

The Home Gateway downstream spectrum was unaffected by these emissions and is shown in the chart below.

Figure 32 Link 2 Downstream - House C – Position 2 - Magnetic Field



The chart shows a notch in 21 MHz Amateur Radio band with an Amateur Radio signal on 21.205 MHz being clearly visible.

The German NB30 3 metre PLT limit, of 40-(8.8 log f), is not applicable in the UK but is shown here for comparison purposes.

Leakage Emissions from PLT Customer Premises F

This location is approximately 180 metres from the Ancaster Road substation. All measurements were made at the single location shown below which was 3 metres from the outside wall of the premises

Figure 33 PLT Customer Premises F in Drummond Terrace

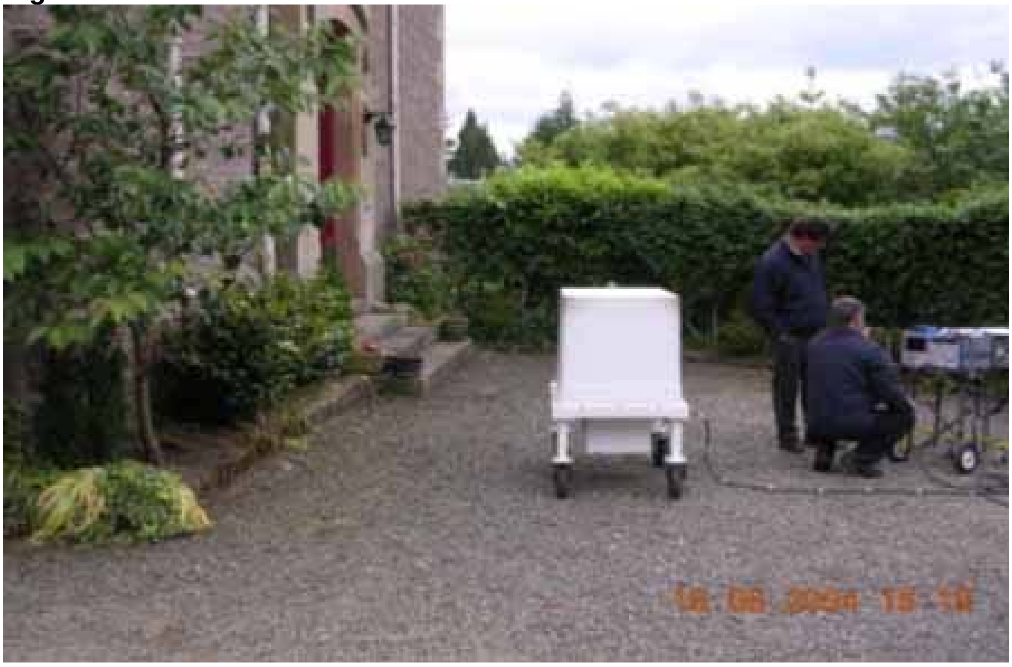
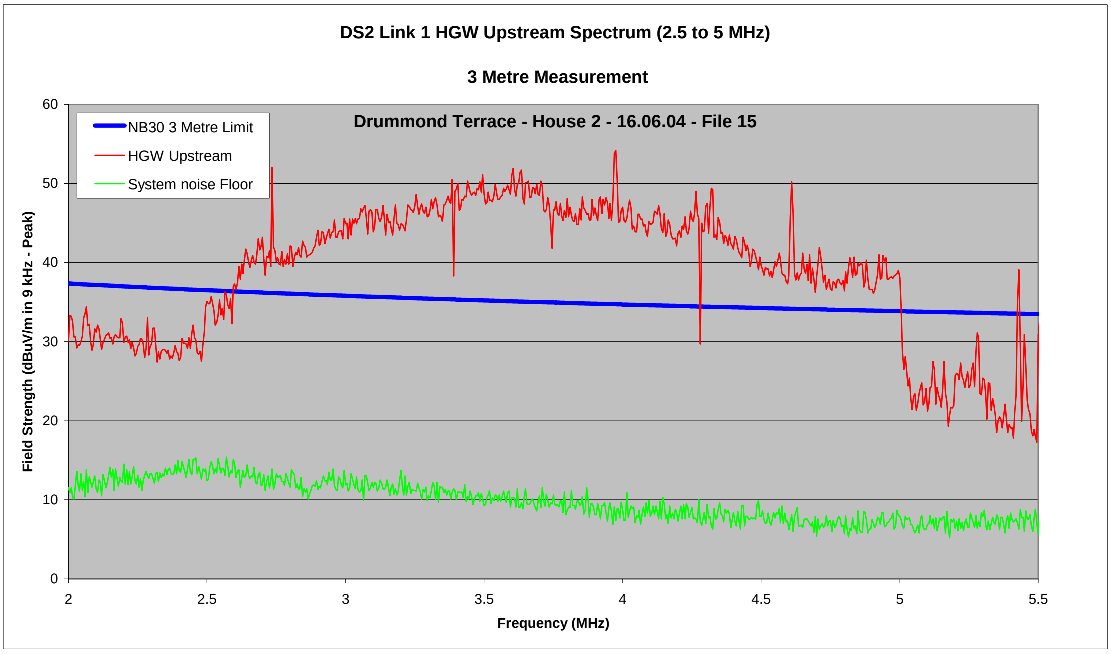
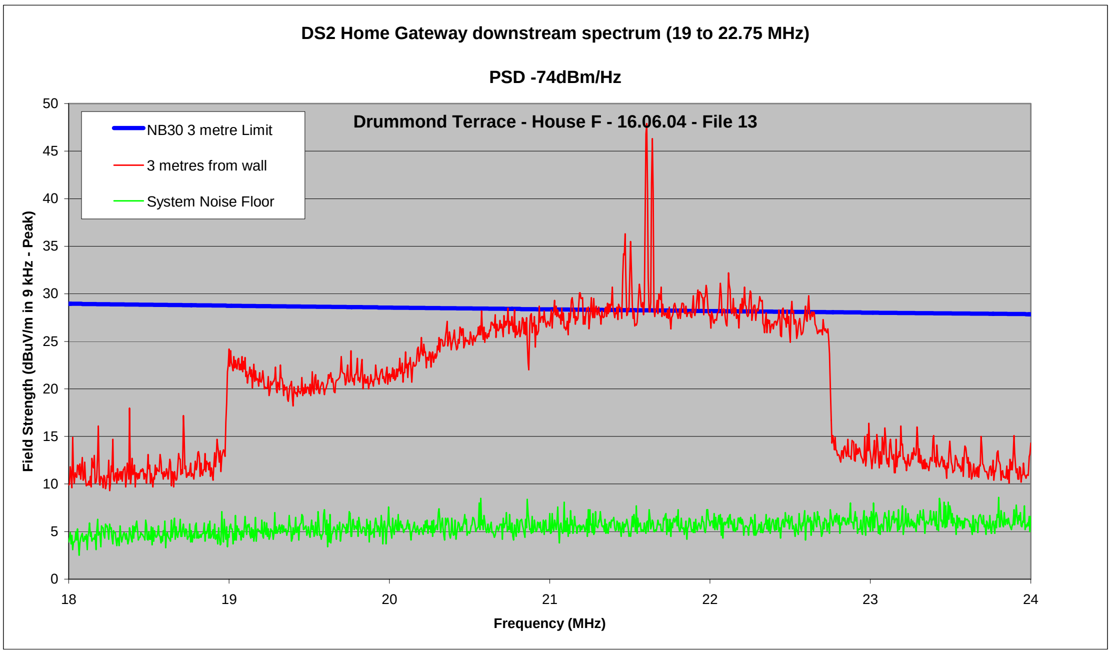


Figure 34 Link 1 Upstream Spectrum - House F - Drummond Terrace



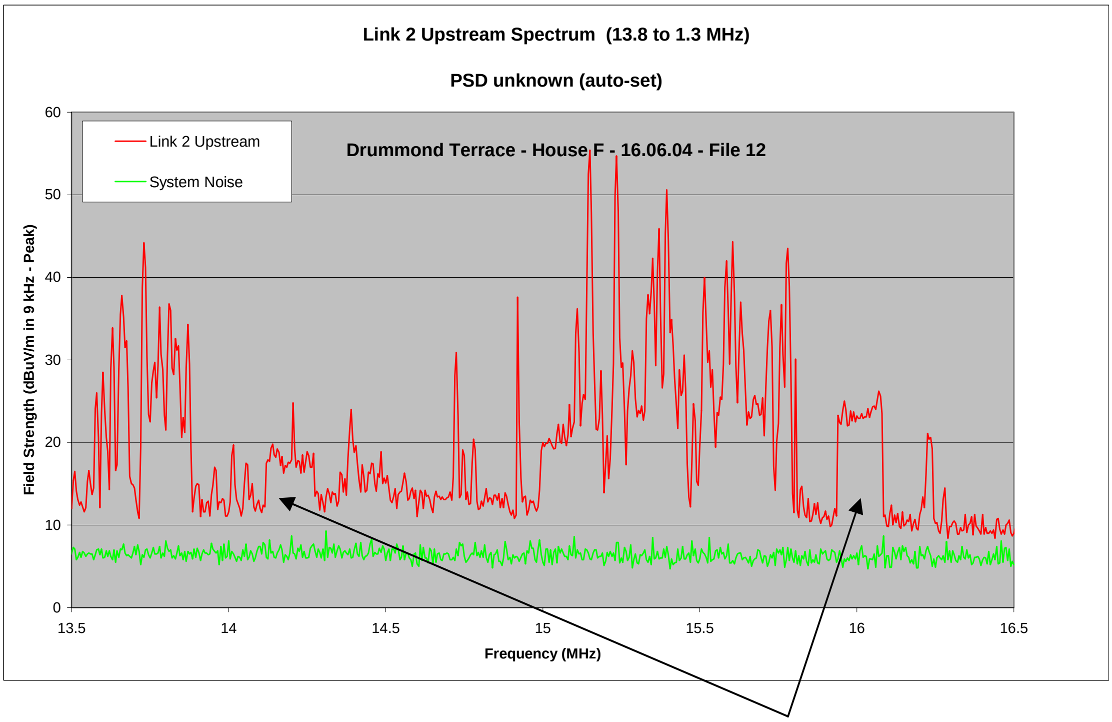
Upstream PSD is under control of the Head End master unit and was unconfirmed in this case. The German NB30 3 metre PLT limit, of 40-(8.8 log f), is not applicable in the UK but is shown here for comparison purposes.

Figure 35 Link 2 Downstream Spectrum - House F - Drummond Terrace



The German NB30 3 metre PLT limit, of 40-(8.8 log f), is not applicable in the UK but is shown here for comparison purposes.

Figure 32 Link 2 Upstream Spectrum - House F - Drummond Terrace



Truncated PLT spectrum due to upstream data bursts from the customer's modem to the Home Gateway unit.

Section 6

Observations & conclusions

Notching

The notches required by Ofcom were applied to both the downstream access spectrum transmitted from the Head End master unit in Ancaster Road substation and separately to the downstream in-house spectrum transmitted from the Home Gateway master units in customer premises. Notches were not applied to the upstream spectrum – *see later*.

S&SE have Jeizer™ network management software, or similar, that enables them to apply notches on demand from their PLT control centre. However, the notches required for this work were requested in advance by DS2, pre-programmed and applied during the testing by their on-site representatives. It is not known whether the two processes are essentially different but if there are differences, it must be presumed that the DS2 method, used for this work, has given the best results currently obtainable.

Measurements of the conducted DS2 signal at Ancaster Road substation confirmed that the depth of both 20dB and 30dB notches, was as claimed. It was found that these values were maintained when the notched spectrum was measured as a radiated leakage emission in other parts of the Ancaster Road network. This aspect addresses some speculation that intermodulation may occur within a PLT network and cause spectral re-growth within the notches. There was no obvious evidence of this.

The 20dB notches appeared to be relatively straightforward to implement and had a sharp cut-off with minimal unintended loss of spectrum bandwidth.

This contrasts with the 30dB notches that required the calculation and application of an algorithm to modify the characteristics of individual carriers within the OFDM spectrum. Although the 30dB notch depth was always achieved, the notch shape appeared more variable and in most cases resulted in a very substantial loss of wanted bandwidth.

At the time of these tests, the calculation and application of the 30dB notch algorithm had not been automated and was carried out on a case by case basis, by DS2 at their Spanish headquarters. It seems likely that, due to the substantial loss of wanted bandwidth and algorithm complications, the 30dB notch will be reserved as an interference mitigation measure of last resort rather than being something that could be more readily used by network operators.

It should be noted that DS2 were unable to apply notching in an upstream direction from either of the slave units. Whilst this is presumably because it would have conflicted with the dynamic power control of the slave units by the master units, it does nevertheless represent a very significant shortcoming in the general promotion of notching as an interference mitigation panacea.

It is understood that later generation PLT products, based on DS2's 'Wisconsin' chipset will be significantly more configurable and will support upstream notching. This appears to be a promising development which may warrant future testing if deployed in the UK.

Launch Power Levels

The PLT launch power levels quoted in this report are those stated by DS2 at the time each measurement was made. They are believed to be correct but, as with all previous measurements of PLT networks by Ofcom and RA, it was not possible to confirm the launch power by calibrated measurement. This has been due to the lack of any standardised interfacing network designed specifically to connect calibrated test equipment to the output ports of PLT modems or couplers.

DS2 stated that the PLT network at Ancaster Road was able to operate satisfactorily at a fixed downstream launch power of -62dBm/Hz due to the low signal to noise ratio performance of their product. This level was claimed to be sufficient to provide S&SE's broadband service to 6 PLT customers, one as far as 230 metres from the launch point. If confirmed, this would appear to be a significant advance on earlier generation PLT products that have required up to 12dB more power to produce the same performance.

It is clear, however, that even if all 6 customers on the Ancaster Road network had been using their broadband service to its full potential at the same time, this would have required only a small percentage of the available bandwidth of the DS2 product. Were the network to have been operating near to its maximum capacity, then it follows that most of the bandwidth would have been required. In these circumstances it is likely that a higher launch power would have been needed to account for signal to noise ratio problems arising in those parts of the DS2 access spectrum that are occupied by, and suffer ingress from, high level broadcast band signals.

In considering the potential for radio interference that leakage emissions from any PLT network represent, it is not the launch power used for a small scale well controlled measurement programme that is of primary importance, but rather the launch power that will be used by network operators on an everyday basis in order to ensure a reliable service to their paying customers in the face of intermittent wide band noise due to arcing thermostats and switch mode power supplies. For this reason leakage emission level measurements are normally carried out at maximum system power because this will be what operators will want to use.

It is recommended that any future measurements are made at the maximum power capability of the product.

Outdoor Leakage Emission Levels.

Except where noted in the results, the leakage emission levels measured and presented in this report were as expected having regard to the measurement position, distance from the source, power applied and the results of previous work. **(Refs 1, 5, 6, 7, 8 & 9)**

There were two locations where it was possible to make close approximations to a standard 3 metre regulatory measurement. At these, the leakage emissions radiated from in-house wiring, due to the Home Gateway downstream spectrum, were at levels very close to the German NB30 radiated emission limit. **(Figures 32 & 35)** These levels were those obtained with the Home Gateway units set at their minimum downstream power setting of -74dBm/Hz. It should be noted that 24dB more power is available if needed. At one location **(Fig 34)** a 3 metre measurement of the Home Gateway upstream spectrum radiated from in-house wiring exceeded the German NB30 limit by approximately 15dB. The power setting in use, under automatic control of the Head End master unit to achieve a satisfactory signal to noise ratio, was unconfirmed.

Indoor Leakage Emission levels

No measurements were made inside a PLT customer premises or inside adjacent premises, but in their absence some simple deductions can be made.

As a starting point it is reasonable to assume that leakage emission levels measured inside a PLT customer premises would be higher in level than those measured outside at 3 metres from the wall. Previous work has shown that a 20dB/decade distance correction factor is applicable between 1 and 3 metre measurements. **(Ref 5)**

Taking account of the 3 metre measurements of the Home Gateway downstream leakage levels, from this report, **(Figures 32 34 & 35)** and adding 9.54 dB (20 log 3/1) would give the minimum levels likely to be seen in positions within a PLT user premises that a victim radio receiver might be located. The level in directly adjoining premises, that are not PLT customers, is likely to be similar.

Measurement Considerations

The low noise floor of the measuring antenna used for this work was the key to securing the results presented.

Had a typical standard 60cm CISPR loop antenna been used, the measuring system noise floor would have been around 30dBµV/m. The charts produced for this report show that, in those circumstances, it would not have been possible to demonstrate the full depth of the notches, as a radiated measurement.

It can also be seen that many of the charts would not have displayed much useful information had the system noise floor been 30dBµV/m and in some cases, all the information contained was at a lower level than that, so a chart would have shown nothing at all.

This situation illustrates the misleading inadequacy of a standard CISPR loop antenna for the EMC compatibility analysis of PLT leakage emissions when the ambient noise floor is often 20 to 40dB below the level that can be measured with it.

It is recommended that for research purposes all future PLT leakage emission measurements, made by or on behalf of Ofcom, use a low noise antenna having similar performance to the product used for this work.

Section 7

Calibrated measuring equipment

DESCRIPTION	MANUFACTURER	Model Number	RTCG Plant
EMI Measuring Receiver	Rohde & Schwarz	ESCS30	2840
EMI Measuring Receiver	Rohde & Schwarz	ESCS30	3178
60cm Active Loop Antenna	Rohde & Schwarz	HFH2-Z2	2115
Low Noise Active Loop Antenna	Rohde & Schwarz	HM525	Ex Contract
Short Active Dipole Antenna	Schwarzbeck	EFS9219	On loan from BT Exact
RF Current clamp	Schaffner	SMZ11	Ex Contract
Spectrum Analyser	Rohde & Schwarz	FSU3	3287

Section 8

References

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   RA / Baldock Report No. ML2 014/02 November 2002
   http://www.ofcom.org.uk/research/industry_market_research/technology_research/emc/?a=87101

2. **The effects of power-line telecommunications on broadcast reception:**
   BBC R&D White Paper 67
   http://www.bbc.co.uk/rd/pubs/whp/whp067.shtml

3. **PLT and broadcasting - can they co-exist?**
   BBC R&D White Paper 99
   http://www.bbc.co.uk/rd/pubs/whp/whp099.shtml

4. **'Specification for the Measurement of Disturbance Field from Telecommunication Systems and Networks in the Frequency Range 9 kHz to 3 GHz'**
   RegTP 322MV05 (part 1) October 2001
   http://www.regtp.de/en/index.html

5. **Ascom PLT Measurements in Winchester**
   Ofcom Report 793 (part 1) November 2004

6. **Ascom PLT installation at S&SE Maidenhead**
   RA / RTCG Whyteleafe Report 612 September 2002

7. **PLT Measurements at Campbeltown**
   RA / Baldock Report No. ML2-017-03 June 2003

8. **The compatibility of VDSL and PLT with radio services in the range 1.6 to 30 MHz**
   RA Report of the UK Technical Working Group October 2002
   http://www.ofcom.org.uk/static/archive/ra/topics/interference/documents/twg-finalreport.pdf

9. **Leakage Emissions from ADSL and PLT Networks**
   RA Presentation to the RRAC annual open forum November 2003
   http://www.ofcom.org.uk/research/industry_market_research/technology_research/rrac/rr_forum2003/?a=87101

Section 9

Acknowledgements

Ofcom would like to thank the following organisations for their support during the course of this work.

Scottish & Southern Energy plc:

for hosting this work, permitting controlled access to the PLT equipment in Ancaster Road substation and for negotiating access for measurements at two of their PLT customer's premises.

DS2:

for providing technical information on the operation of their product, for scripting the spectrum notches required during the course of this work and for providing on-site assistance during the measurement phase.

BBC R&D:

for undertaking an on-site assessment of the effect of DS2 PLT leakage emissions on sound broadcast reception in the short wave spectrum.

DTI CII division:

for sending a representative to witness some of the measurements.

Annex A

List of abbreviations

ADSL	**Asymmetric Digital Subscriber Line**
BPL	Broadband (over) Power Line (USA)
CISPR	International Committee for the study of Radio Interference
DTI	Department of Trade & Industry (UK)
DRM	Digital Radio Mondiale
DSSS	Direct Sequence Spread Spectrum
EMI	Electromagnetic Interference
EMC	Electromagnetic Compatibility
GMSK	Gaussian Minimum Shift Keying
LV	Low Voltage
OFDM	Orthogonal Frequency Division Multiplex
PLC	Power Line Communications
PLT	Power Line Telecommunications
PSD	Power Spectral Density
RA	Radiocommunications Agency (subsumed into OFCOM UK Jan. 2004)
Reg TP	Regulator of Telecommunications & Posts (Germany)
RMS	Root Mean Square
RTCG	Radio Technology & Compatibility Group
SDSL	Symmetrical Digital Subscriber Line
S&SE	Scottish & Southern Energy plc (Major UK Power Utility)

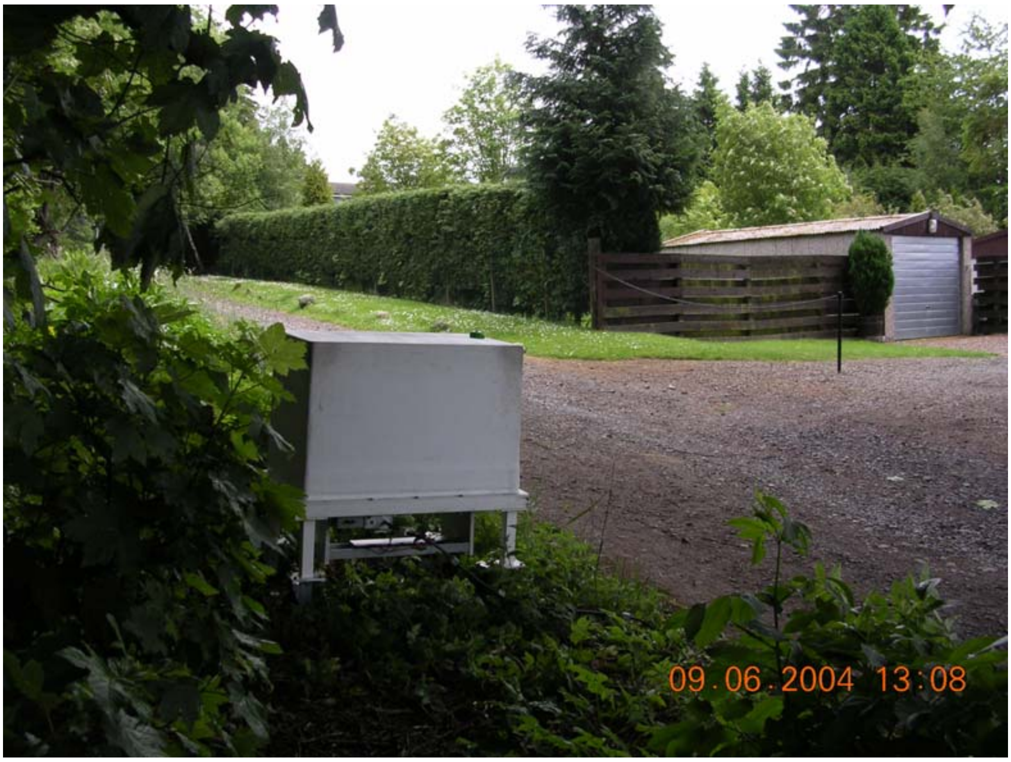
Annex B

Measurement location photographs

Location 2 – Outside ‘Overdale’

Location 3 – Outside ‘Treetops’

Location 4 – Outside ‘Rumbleden’



Location 5 – Outside ‘Pinewood’